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CARBORUNDUM: A NEW ARTIFICIAL ABRASIVE MATERIAL.

[*Being the report of the Institute through its Committee on Science and the Arts on the invention of E. G. Acheson, of a new Artificial Abrasive Material.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 3, 1894.

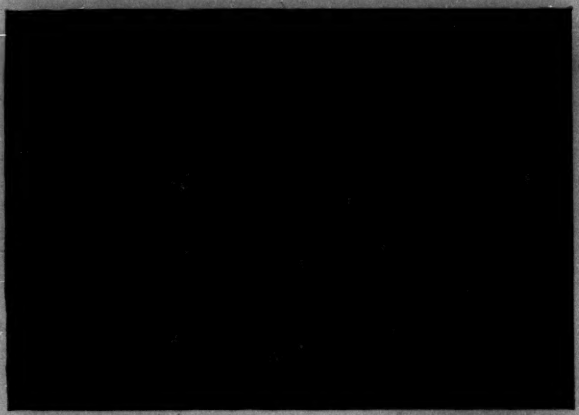
The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting by its Committee on Science and the Arts, investigating the invention of Mr. E. G. Acheson, of Monongahela City, Pa., of an artificial crystalline carbonaceous substance, termed by the inventor, "carborundum:"

Finds that the invention is the subject of letters patent of the United States, No. 492,767, of February 28, 1893, granted to Edward G. Acheson, a copy of which accom-

panies this report* and may be referred to for descriptive and other details not herein incorporated.

The patent above referred to describes the manufacture of a crystalline compound, composed essentially of silicide of carbon, and embraces in its claims both the general method of manufacture and the product.

The primary object of the invention is stated to be the production of a carbonaceous material having properties which will render it useful as a substitute for diamond, bort, corundum and other abrasive materials.



Exterior view of electric furnace for making carborundum.

The method of manufacture consists in general in subjecting to an extremely high temperature, and for a considerable time, mixtures of carbon with silica or silicious materials and a suitable flux.

The inventor finds that the heat generated by an electric current affords him the most efficient conditions for securing the high temperatures needed to bring about the reac-

* Copy of this specification is filed with the record of the case.

tion, and accordingly states his preference for the use of the electric furnace.

The following general description will serve to explain the mode of operation. An intimate mixture of carbon and sand is introduced into a rectangular box of brick or fire-clay constituting the furnace chamber, the mixture being so placed as to surround a core of granular carbon. Into each end of the chamber project several rods of carbon making connection with the core, and through these rods and the core is passed a current sufficient in quantity and for a sufficient length of time to fuse the contained silica and bring about its subsequent combination with a portion of the carbon to form a new substance, a silicide of carbon, to which the name of carborundum has been given.

Upon removal from the furnace, the carborundum is found as a porous, cinder-like mass, formed of groups of small, glittering crystals of yellowish-green, bluish-green, or blue color, surrounded by more or less coherent masses of partly altered carbon.

The separation of the carborundum from the other constituents of the mass is first effected as completely as may be by hand. The selected material is washed in water, then treated with acid to remove soluble impurities (iron, alumina, lime, etc.), again washed, then dried and crushed. By this means the individual crystals are separated, and the purified material is then separated into commercial sizes of different degrees of fineness by a process of floatation in a current of water, the several grades being thus automatically collected in separate receptacles.

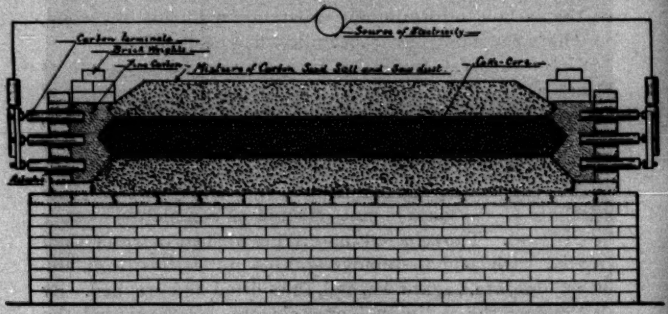
An analysis of the product thus formed shows that it is a compound thus far new in chemistry, a combination of one atom of carbon with one atom of silicon, or, in chemical terms, a silicide of carbon, having the formula SiC.* The reaction involved consists in the withdrawal by the carbon of two atoms of oxygen from the silica of the sand or

* For a very full and detailed account of the method of manufacture, the chemical and crystallographic properties of this compound, see this *Journal*, **136**, 194 *et seq.* Art. *Carborundum: its History, Manufacture and Uses*, by E. G. Acheson.

clay, and the combination of the nascent silicon with a portion of the surplus highly heated carbon, according to the equation,

$$SiO_2 + 3C = SiC + 2CO.$$

It is well known to chemists that the formation of a silicide of carbon by the direct reduction of silica with carbon has hitherto been impossible at any temperature attainable in the laboratory. By the employment of the heating effect of the electric arc in a furnace of the simple construction described above, in which the heat can be confined, the temperatures obtainable are so much greater than can be realized by any

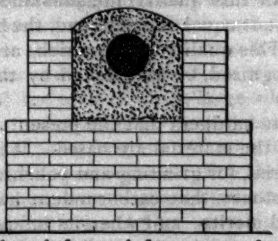


Longitudinal section through furnace before passage of current.

other known methods, that reactions heretofore deemed impossible are readily effected. In the hands of Moissan and others, the electric furnace has lately been made to yield results of a nature as extraordinary and unlooked-for as those which followed upon the first application by Davy of the voltaic battery to effect chemical decompositions. In employing the electric furnace method, therefore, to bring about the desired results, Mr. Acheson deserves the credit of having applied the only method by which it could have been successfully accomplished.

At this point it is worthy of notice that Moissan, whose recent experimental work with the electric furnace has greatly extended our knowledge of chemical reactions tak-

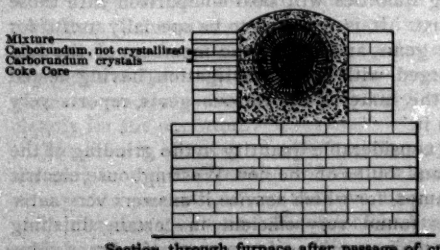
ing place at enormously high temperatures, produced this same compound (SiC) and described its properties in a communication presented to the French Academy at the session of October, 1893; also, that Schützenberger formed it by the combined reducing action of *carbon and silicon* on silica. Mr. Acheson's results were obtained and duly announced,



Section through furnace before passage of current.

however, before the publication, by these investigators, of their results.

The interest attaching to this compound, because of its novelty and the mode of its production, is greatly increased by the remarkable properties which it exhibits. Those



Section through furnace after passage of current.

properties which are more particularly referred to are the following:

Permanence.—Being formed at an enormously high temperature, it is natural to anticipate that it would be stable at all temperatures below that of its formation; but in addition to this stability, it appears to be capable of resisting

many of the most powerful chemical reagents. The only reagents that appear to be capable of decomposing it readily are the caustic and carbonated alkalies in the state of fusion.

Infusibility.—The substance appears to rank with the most infusible substances known, yielding only to the heat of the electric furnace.

Hardness.—In this quality, the substance approaches, if, indeed, it does not equal, the diamond, the hardest of known substances. This quality is one which, at first, would not readily be recognized, being masked by the brittleness of the crystals.

It is upon its hardness that the present and prospective applications of the material are based. It is, in brief, as an abrasive material, for grinding and polishing metals, glass and precious stones, that carborundum has been found to possess decided merits; and when its unique physical characteristics are so thoroughly understood that they may be utilized to the best advantage, the material, in all probability, will rank among the most valuable abrasives known to the arts. It was first usefully applied for the cutting and polishing of diamonds and other precious stones, and from reliable evidence presented in the course of this investigation, its cutting qualities will bear comparison with those of diamond dust. It is reported to be specially useful for polishing such gems, and one of the members of the sub-committee charged with this investigation, having tested the merits of the material on various gems, reports very favorably upon it.

It is used in considerable quantity in the grinding of the glass stoppers and bulbs of the new Westinghouse electric incandescent lamps, for which service it answers very satisfactorily. It is found very efficient in certain finishing operations in machine work, as, for example, for brass valve grinding. Of late, it has been introduced in the form of small wheels, discs and points for use in dentistry in place of the corundum tools in general use, and finally, it has just been introduced in the market in the form of wheels of large size for general grinding and cutting purposes in machine work as a substitute for emery wheels.

The sub-committee charged with this investigation was supplied with a considerable number of samples of the material, in powder form and made up into wheels, with which to make trial of its usefulness. The results are given in what follows:

A number of wheels of the sizes and grades indicated as most suitable for certain special uses were sent to a number of machine shops, whose proprietors had expressed their willingness to test them. (Their reports form part of the record of this case and are accessible for reference.)

The results of the tests of these large wheels were very contradictory, the wheels being pronounced very satisfactory by some, and being condemned by others, but in the main, the verdict was unfavorable. The absence of concordance in these results would seem to indicate the existence of faulty methods of manufacture, possibly the use of unsuitable binding material. It is certainly not unreasonable to assume that, when more experience has been gained with carborundum and its peculiar physical qualities are better understood, more uniform and better results may confidently be looked for.

The smaller wheels and points made for dentists' use were found to cut porcelain much faster than wheels of corundum and shellac of the corresponding sizes and grit, and to wear away more slowly than the latter. When used dry they cut faster than dry corundum wheels and do not glaze so readily as these. This quality makes their use cleanly for the operator.

The results of these practical trials may fairly be summarized in the statements that the new material possesses remarkable properties as an abrasive, being the first artificial substance thus far produced which compares favorably with bort in hardness and which is capable of being used as a substitute for it, that when its peculiarities are better understood it should be capable of yielding cutting wheels of high efficiency to take the place of abrasives in common use, and that should find general application in the arts wherever its price is not prohibitory.

In consideration of the facts set forth, the Institute

recommends the award of the John Scott Legacy Premium and Medal to Edward G. Acheson, for his discovery of a new and valuable artificial abrasive material.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, February 7, 1894.

JOSEPH M. WILSON, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
ARTHUR BEARDSLEY, *Chairman.*

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ON GAS BURNERS, GAS PRESSURE REGULATORS AND GOVERNOR BURNERS, GAS GLOBES AND GLOBE HOLDERS, AND GAS FIXTURES.

BY WM. PAUL GERHARD, C.E.,
Consulting Engineer for Sanitary Works, New York City.

[*Continued from p. 343.*]

II.—GAS PRESSURE REGULATORS.

It is a well-known fact that the gas pressure in the supply mains is constantly fluctuating, and that, at times and in certain districts, it is greatly in excess of what is required for proper combustion at the burners. Consumers are made aware of such excessive gas pressure by the roaring, hissing or singing gas flames, by irregularly shaped gas jets and cracked globes, by the jumping up of flames and other irregularities.

It is a popular fallacy that gas companies wilfully put on a high pressure at the works in order to make the consumers' meters go faster. A moment's reflection ought to convince any fair-minded person that this is not the case. If the above supposition were true, the gas companies would be the losers in two ways, viz.:

(1) A high pressure leads to a larger loss by leakage at the joints in the street mains, a loss usually estimated at

from seven to ten per cent. of the total gas output, but often largely in excess of this amount.

(2) An excessive pressure would mean an increased consumption, or rather waste, of gas in all street lamps having ungoverned burners and which are not supplied through a meter, but for which gas companies are paid a fixed sum per year.

It is, nevertheless, true that it is impracticable for gas companies to maintain a constant pressure in the street mains.

In a town of small extent, with absolutely level districts and with centrally located gas works, a gas pressure of $\frac{1}{10}$ inches of water would be ample to supply all consumers. Such conditions, however, are quite exceptional, and, as a rule, owing to variations in levels of various districts, owing to various diameters of the gas supply mains, owing to the unavoidable friction in the pipes and the extreme distances to which gas has to be conducted from the works, the gas works are obliged to put on a high pressure, in order to insure a sufficient supply to the most distant consumers and to those located in low-lying districts. Again, the pressure in the house pipes and at the burners changes with the varying number of burners lit at one time in a dwelling, and also, and much more so, with the varying consumption in a street or in a district. These unavoidable fluctuations of pressure range from $\frac{1}{10}$ to $\frac{4}{10}$ inches of water pressure.

The evils of high gas pressure have long been recognized, and efforts made to avoid the same. An excess of pressure at the gas burner means imperfect combustion, loss of illuminating power, vitiation of the atmosphere, blowing and hissing gas jets and a wasteful use of gas. In speaking of burners, I have already stated that a high pressure and small burners are not to be recommended; that on the contrary, ample volume of gas, issuing at a low pressure, from large burners, are desirable conditions for successful gas illumination.

The following results of experiments, taken from an able paper by Mr. Butterworth, the general manager of the

Columbus (O.) Gas Company, exhibit clearly the evil effect of over-pressure at the burner:

	Table I. Common 3-foot Burner Tip.					Table II. Common 5-foot Burner Tip.				
Pressure,	1	1	1	1	1	1	1	1	1	1
Consumption in cubic feet per hour,	5·70	7·55	9·15	10·40	11·45	7·45	9·70	11·50	13·15	14·20
Candle-power,	13·36	16·62	17·64	18·88	17·08	16·32	21·96	23·28	21·80	20·28
Candle-power per cubic foot of gas consumed,	2·344	2·201	1·927	1·815	1·492	2·191	2·264	2·025	1·658	1·428

These experiments demonstrate the enormous waste of gas occurring with common burners, where no attempt is made to regulate the pressure. They also show that high pressure means a loss in candle-power; for whereas the consumption of gas doubled, the efficiency of the burner decreased fifty-seven per cent. for the three-foot burner, and fifty-three per cent. for the five-foot burner, showing a slight advantage in favor of the larger burner.

There are various ways in which the gas pressure in the house pipes or at the burners may be controlled and checked. One rough method consists in throttling the main gas cock at the gas meter, and another in turning the gas keys at each fixture, *i. e.*, at the burners. Both methods, however, are unsatisfactory and unreliable, because the control of pressure is not automatic, and because it would obviously be impracticable to require the consumers to devote care, time and almost constant attention to the continual adjustment of the burner keys, made necessary by the constant fluctuations in the pressure.

A multitude of *check burners* have been devised, all having in view a retardation of the velocity with which gas escapes at the burners. This they accomplish to a certain extent, but as the obstructing material is, as a rule, fixed in the burner and cannot be adjusted, whereas the pressure fluctuates constantly, it is obvious that check burners cannot and do not attempt to regulate the flow of gas or govern the pressure. Even the best of check burners, having adjust-

able checks, would require a frequent adjustment during the evening hours and, therefore, would have no advantage over the simpler method of checking the flow by turning the gas keys. All that can really be said in favor of check burners is that they are better than the common gas burners and that they are somewhat cheaper than automatic governor burners. The Empire burner, the Young America, the Broenner, Leoni and Bray burners, Sugg's "Winsor" burner, Gregory's mica check burner and Silber's batswing burner, having a lower chamber in which the gas expands and thus escapes at the slit of the burner tip under diminished pressure, are examples of this class.

From Mr. Butterworth's paper I quote again two tests of consumption and efficiency, made with a five-foot Empire check burner and a No. 6 Bray special burner:

	Table III.					Table IV.				
	5-foot Empire Check Burner.					No. 6 Bray Special Burner.				
Pressure,	1/8	1/6	1/4	1/3	1/2	1/8	1/6	1/4	1/3	1/2
Consumption in cubic feet per hour,	3·10	4·05	4·85	5·50	6·05	6·29	7·75	9·10	10·25	bl'w'g
Candle-power,	9·24	12·44	15·18	16·74	18·04	15·60	18·56	20·74	22·72	—
Candle-power per cubic foot,	2·981	3·071	3·129	3·044	2·982	2·557	2·395	2·279	2·216	—

It is evident, from the above observations, that check burners do not prevent wasteful use of gas, that they do not control gas pressure and that the gas consumption of check burners necessarily varies with the pressure. In the above tests the consumption of the Empire burner was nearly doubled when the pressure increased from $\frac{1}{8}$ to $\frac{1}{2}$, whereas the candle-power per unit of gas consumption remained the same.

While the gas works may, by using station and district governors, reduce, or control to a certain extent, the pressure in the street mains, it is obviously desirable that the consumers should use means in their houses for controlling the gas pressure automatically. Gas companies long ago recognized the evils of excessive pressure, and also the fact

that economy in lighting depends upon its efficient control. Where they undertake to furnish public illumination of streets and squares by contract with the city for a stated fixed annual sum of money for each street lamp, they therefore, applied to the burners automatic means for controlling the pressure and thus preventing waste of gas.

Two entirely different methods may be adopted by the consumer to effect an automatic control of the gas pressure. He may apply an automatic gas governor on the house service pipe at the meter, which regulates and reduces the pressure in the whole house pipe system, or else he may use automatic gas governor burners, which control the volume of gas supplied to each light separately, establishing a constant consumption at each burner, while leaving the full pressure in the house pipes.

There are a large number of *gas pressure regulators* in the market, and as it is the chief object of this paper to point out to the consumer that there are means available for efficient control of the gas pressure, rather than to offer a detailed description of these devices, many of which are quite similar in principle and in construction, I will simply state that there are two kinds of pressure regulators, namely, the dry and the wet regulators, the former using a leather diaphragm, whereas the latter use a float, cup or bell, dipping either in glycerine or else in mercury.

The Sugg diaphragm pressure regulator and Peebles' diaphragm regulator are examples of English devices of the first class, whereas the Stott, Shaw, Sugg, Bower, Ewart, Brown's "Excelsior" and Peebles' mercury, are English pressure regulators belonging to the second class.

The "National" automatic and the Amick gas regulators are American liquid governors, having a brass globe floating in a seal of glycerine, and the Beattie, O'Gorman and Patterson regulators are examples of American mercury seal regulators. Some of these are obtainable for sale, whereas others are only placed on rental in the houses of consumers by companies obtaining a revenue from the saving effected, as shown by the monthly gas bills.

It is an essential condition, where pressure regulators

are applied, that the house pipes should be very ample in size, that there are as few elbows or bends in the pipes as possible, and that the tubing of gas fixtures, the aperture of gas keys and the slits of the burners are large; in other words, that the volume of gas supplied to the burners is ample, otherwise the inevitable result of a control of pressure is a paucity of light. Therefore, such pressure regulators should never be used by consumers where the above conditions are not complied with, otherwise the remedy might prove worse than the evil complained of. It is equally useless to apply pressure regulators to houses in low-lying districts where the pressure is already low. In all cases the saving in gas consumption, which is the result of a reduction in gas pressure, should be effected without any loss of illuminating power.

A pressure regulator placed on the service pipe of a house reduces an excessive gas pressure and secures a tolerable uniformity of pressure and supply at all burners; but this is only true of buildings with small floor area and of few stories in height. For large factories and halls with many lights on the same level, where the whole number is always lighted, a pressure regulator will answer. In the case of large buildings and in all buildings of many stories, on the other hand, an absolutely uniform pressure is not attained, because no matter how well the distribution pipe system has been calculated and arranged, there is necessarily some loss of pressure through friction in long pipes and at elbows, so that the gas at burners situated at a distance flows at a lower pressure. Owing to its specific gravity, which is not quite one-half that of air, gas tends to gain in pressure with increased elevation, each rise of ten feet vertically adding one-tenth inch of water pressure. This explains why, in high buildings, even with a pressure regulator at the meter, the gas pressure increases for each floor, causing the burners in upper stories to "blow." Therefore, the better method in such cases is to provide a governor on each floor.

It is sometimes feasible in cases where the number of burners lighted remains constant, and where the pressure

varies only slightly, to control and reduce the pressure on each floor level by a governor, and in addition to use a good check burner at the fixtures. Sugg's "Winsor" screw regulating burner has been devised with this special object in view.

The best and surest remedy, undoubtedly, consists in the use of automatic acting *governor burners* at all fixtures. Governor burners must not be confounded with check burners, which only retard, whereas governor burners regulate, the flow of gas in such a way that, as the pressure increases, their regulating action increases and *vice versa*. Such governor burners cause the gas to issue at the burner in a constant volume, no matter what the pressure in the service pipe is, hence the name "Volumetric" burners is sometimes applied to them.

The first automatic regulating burners were devised for street lamps, and they were sometimes very clumsy in shape, casting large shadows downwards. They have been much improved of late years, and now there are several good governor burners obtainable which are compact in shape and which act almost perfectly in regulating the supply to the burners, and in preventing gas from flowing out under excessive pressure. Even governor burners, however, may in time clog up, and will require occasional cleaning.

There are many different makes of volumetric burners, and it is not my intention to describe any of them in detail. Briefly stated, the flow of gas is controlled in them by a light cup, cone or disc, placed in an enlarged chamber of the burner, which floats up or down as gas pressure increases or diminishes, and being connected with a valve at the entrance to the burner, it opens or closes the same, and thus causes more gas to be admitted when the pressure fails, and when the pressure rises it reduces the supply.

Volumetric governor burners are equally applicable to flat-flame, round-flame, regenerative and incandescent burners. The best regenerative lamps are always fitted up with such a regulator, and likewise are the Argand and flat-flame burner lamps of the highest make always sold with them.

Among the best-known governor burners I mention those

of Giroud, Wilder, Sugg, Peebles and Lux, the first one being a French burner, the second a burner of American make, the third of English, the fourth of Scotch make, and the last one being a German volumetric burner.

Other burners, not so well known or extensively used, are the Rappleye rheometric governor burner, endorsed in 1882 by the Committee on Science and Arts of the Franklin Institute; the Champion burner, patented by Van Wies in 1890; the Chamberlain, Boore and Jackson burners, all of American make; the Schuelke adjustable gas governor burner, of German make, and the Orme, Hawkins and Acme burners, of English make, the Hawkins burner being the only governor burner with union jet tip known to me.

My list does not pretend to be exhaustive, and it is quite possible that I may have unintentionally omitted some good burners which have not come to my notice.

The Wilder volumetric governor burner is the invention of Moses G. Wilder, M.E., of Philadelphia, who obtained a patent for it in 1880. This burner is a good example of an American governor burner, and it is suitable not only for flat-flame and Argand burners, but also for regenerative lamps and for the Welsbach incandescent light. The maker, in describing it, states that it is not a pressure reducer or regulator, that the flow of gas through it is not changed by very wide variations of pressure, and that it secures a uniform rate of supply to the burner, with little or no reduction of pressure.

The inventor of the Boore burner, Mr. Lewis Boore, of Buffalo, N. Y., states that he endeavored to produce a reliable and simple automatic governor burner of low cost, which would indicate practically correctly for a very wide range of pressure, without having such an extreme accuracy or such close adjustment as to destroy its utility.

Wm. Sugg & Co. make two kinds of volumetric burners, a steatite float governor and a leather diaphragm governor burner.

Sugg's patent "Alexandra" governor burners combine great economy with efficiency, and produce a brilliant, white, silent light. They are fitted with steatite float governor,

and the superior light attained is also a result of adopting double annealed Albatrine globes with wide opening. An even better flat-flame burner by the same maker is Sugg's patent "Christiania" governor burner, fitted with a specially prepared leather diaphragm governor, with Sugg's patent table top circular slit steatite burner tip. Sugg's London improved Argand burner always has a governor burner attached to the fixture.

Mr. Wilder calls attention to the fact that his governor burner, to operate well, requires a full street pressure. This rule is applicable to all volumetric burners; hence, where these are used, a pressure regulator should not be used at the meter.

In order to show, by actual experiments, how nearly uniform the consumption of gas remains with governor burners, I refer the reader again to Mr. Butterworth's able paper on governor burners, wherein is published the following table, showing the gas consumption of a number of such burners under varying pressures:

TABLE V.

Pressure,	$\frac{1}{10}$	$\frac{2}{10}$	$\frac{3}{10}$	$\frac{4}{10}$	$\frac{5}{10}$	$\frac{6}{10}$	$\frac{7}{10}$
	cu. ft. per hr.	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*	*cu. ft. per hr.*
Six-foot governor burner,	6·20	6·20	6·35	6·30	6·25	6·25	6·40
Six-foot governor burner,	5·95	6·50	6·20	6·20	6·05	6·15	6·05
Five-foot governor burner,	4·50	4·50	4·55	4·55	4·65	4·65	4·60
Five-foot governor burner,	4·50	4·65	4·55	4·65	4·70	4·65	4·55
Five-foot governor burner,	4·90	4·95	4·95	4·95	4·90	4·90	4·90
Adjustable burner,	5·60	5·50	5·40	5·30	5·07	4·80	4·60
Adjustable burner,	4·96	5·97	6·21	6·19	6·05	5·89	5 69
Adjustable burner,	4·95	4·95	4·95	4·95	4·95	4·95	4·95

The last burner in the table showed a perfect uniformity of supply under the wide range of pressures used in the test. Some of these governor burners are adjustable, and if they are required to pass a certain quantity of gas per hour, a nice adjustment is necessary, which can only be accomplished if the candle power and quality of gas, its pressure and specific gravity are known. A governor burner adjusted for a gas of certain specific gravity would not remain correct for a gas of different density, or for any temperature which would change the density.

Both, the pressure regulators on the main service pipe and the governor burners, accomplish a saving in gas consumption by preventing useless waste, amounting to a reduction of from twenty to forty per cent. in the gas bills. Other incidental advantages gained are: a great improvement in the steadiness of a gas flame without regard to the number of burners lit or the constantly changing street pressure; the hissing or roaring noise, the blowing, and the flickering of lights is prevented; the illumination becomes stronger; the smoking of Argand burners is prevented, and the air of the room is vitiated to a much smaller extent by the products of imperfect combustion. With governor burners, however, these results are attained in a higher degree than with pressure regulators on the service pipe.

To sum up, practical considerations must decide which form of regulation it is best to adopt. In this connection the following rules are to be recommended, viz.:

(*a*) Where the street mains are large and the differences of level insignificant, use either check burners or volumetric burners.

(*b*) Where the street mains are small, or the pressure is low or the house pipe insufficient, neither method of regulation should be employed.

(*c*) Where the town is hilly and there are considerable differences of elevation in the districts, a pressure regulator will answer, provided the house pipes are large, the gas keys full bore, and the building only a few stories in height, and not of great extent laterally.

(*d*) Where in such districts the buildings are high or very large, a pressure regulator on each floor should be used, together with regulating check burners at the fixtures, but in such cases governor burners are a simpler remedy, and are, therefore, to be preferred.

III.—GLASS GLOBES AND GLOBE HOLDERS.

Flat-flame burners are, as a rule, surrounded with glass globes, and practical experience and observation have established the fact that if these are unsuitably arranged or of improper shape, they constitute another factor, caus-

ing deficient illumination, imperfect combustion, and frequently a waste of gas and a corresponding increase in the gas bills.

Gas globes are used chiefly to protect open flames against draught, and thereby to prevent the annoying unsteadiness and flickering of lights. They are also employed to shade the eyes from the direct glare of the light, to diffuse and soften the light, also to add to the good external appearance of gas fixtures; and finally, gas globes are, for safety's sake, placed over naked lights to shield the flame from coming into direct contact with inflammable materials. From all of which it follows that gas globes are used for utility even more than for ornament, hence their design and construction should be based on sound principles.

In order to obtain good illumination, and to avoid the flickering of gas lights, the air necessary for combustion should be brought to the flame in a slow, uniform and steady current. If the air supply is insufficient a flame is apt to smoke and will blacken ceilings and contaminate the air. If the air rushes to the flame in a violent manner, this will destroy the steadiness of the light, the light will flicker and jump, and it has the further detrimental effect of cooling the flame, and thereby reducing its brilliancy.

The old style glass globes were quite defective in shape, form and material. They were made with very narrow top and bottom openings, or if tulip-shaped and widening at the top, the bottom opening was extremely narrow, being often but one and one-half or two inches in diameter, and, where such globes were in use, the ceiling was often the only well-illuminated place. The result was that, owing to the smallness of the bottom aperture, the contracted globe acted like a chimney, causing the air current to impinge upon the flame to such an extent as to seriously disturb the flame, and thereby causing same to flicker in a distressing manner. Another defect of the old style globes is that they form dust traps, and that they are readily soiled in lighting.

If, added to this defect in the globes, the gas pressure at the burner was excessive, the resulting illumination necessarily was very imperfect. To determine the actual loss of

light due to small openings in globes, Dr. Wallace made a series of experiments, which showed the following results:

A naked flame was tested and found to give 16·8 candle light. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two and three-eighth inch bottom opening, gave 15·4 candle lights, or loss of 8·3 per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two and one-quarter bottom opening gave 15·2 candle light, or loss of 9·5 per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with two inch bottom opening, gave 13·6 candle light, or loss of nineteen per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with one and one-half inch bottom opening gave 13· candle light, or loss of twenty-two per cent. The same flame, surrounded with a seven and one-half inch diameter clear globe, with one inch bottom opening, gave 12· candle light, or loss of 28·6 per cent.

All glass globes, moreover, absorb a certain amount of light, and the loss of light and corresponding waste of gas due to this cause increases the more opaque the glass globe is. Fancy "ruby" or other colored, etched or otherwise decorated globes in particular obstruct a large amount of light, and hence increase gas bills by the necessity of keeping a larger number of lights burning on a chandelier. It is stated on good authority that light is obstructed as follows:

	Per cent.
By clear glass globes,	10·15
By slightly ground globes,	24
By globes ground all over,	25·40
By opal thick glass globes,	35·60
By colored or painted globes,	64

Lastly, the globes with narrow bottom and wide top opening are objectionable, because instead of casting light outward and downward by reflection, they throw the greatest amount of light up to the ceiling, where it is not wanted.

It matters little how attractive in shape and artistic in outline such old style globes are; as long as they tend to disturb the flame they are clearly objectionable. These defects have been gradually recognized, and such globes

with contracted openings happily are now being discarded. The new form of globes has wide bottom openings, which admit the air without causing a draft; the shape of the globe is designed more with a due regard to its proper functions than solely from a decorative point of view. Such globes induce a straight, upward, gentle current of air, and the flame remains steady and bright. All globes of modern construction have bottom openings four and five inches in diameter, and have the incidental advantage that a portion of the light falls directly downward without being obstructed.

The Sugg "Alexandra" and "Christiania" burners are surrounded with globes of most desirable shape and material; the Broenner burners have similarly shaped "Cornelian" globes; and Wilder, in the description of his volumetric burner, recommends globes four and one-half inches in diameter at the bottom and five and one-half inches at the top.

Regarding the material for globes, clear crystal glass is the best, because it absorbs the least light. Still, it oftentimes becomes desirable to render the light of a gas flame soft and mellow, and for such cases thin milk-white opal globes are best and quite effective. Sugg uses with his best flat flame governor burners double annealed large size globes, with wide bottom opening, which he calls "Albatrine" globes, and which give a particular softness to the light. The cheaper kind of thick opaque white glass globes should be avoided, as they intercept as much as seventy to eighty per cent. of light.

In connection with globes, it is noteworthy that somewhat increased illumination is obtained by using globe holders which are as little light obstructing as possible, *i. e.*, very thin sheet brass or brass wire globe holders. The old style fixtures had heavy and cumbrous cast brass holders, or heavy discs, triangles or rings, all of which are objectionable, because they intercept a portion of the light, and cast a shadow downward and thereby cause a loss of light. The new shadowless globe holders, made of three simple prongs of brass wire, not more than one-eighth of an inch thick, and

without any rims whatever, are recommended by all dealers in advanced gas light fixtures.

Lastly, the position of the glass globe in reference to the gas flame is of a good deal of importance where it is desired to secure a steady, bright light. It has been found long ago, by experiment, that by arranging a shadowless globe holder on the burner in such a manner as to place the level of the bottom of the flame in line with the bottom edge of the globe, the flame will burn very quietly and steadily, and will not be affected much, if any, by the ascending air current, whereas if the flame is set higher it is apt to flicker.

This correct position and shape of a glass globe has been pointed out repeatedly by such gas engineers as Wilder, Peebles, Sugg, Broenner, Silber and others, in connection with their gas burning appliances; but on the whole, in practice, little attention has been paid to this simple yet efficient rule.

[*To be concluded.*]

EMERY AND OTHER ABRASIVES.*

By T. Dunkin Paret,
President of the Tanite Company.

[*Concluded from p. 372.*]

While small specimens of corundum, in the form of imperfect sapphires, have come from Montana, where the existence of this mineral has long been known, no other locality has yielded corundum except that well-known belt which reaches from Massachusetts to Georgia, and which seems to have its center in the corner where North and South Carolina, Georgia and Tennessee come together. In this belt the localities where corundum occurs are innumerable, but the prevalence of the mineral is a poor indication of its quantity. Corundum occurs in pockets, seams, sand veins, narrow streaks and detached crystals, seldom in large mass. Chester County, Pa., is, apparently, the only locality where large solid masses have been found. The

largest annual product of American corundum has been 645 tons, and, though corundum mining companies have multiplied rapidly during the last few years, the commercial supply has never been more precarious.

Unlike corundum, emery consolidates in large masses. It does not, indeed, form continuous beds of great extent, like coal or iron, but its discontinuous masses and veins sometimes contain hundreds of tons. The emery-bearing locality in Westchester County, N. Y., is a strip from one-half to three-fourths of a mile in width, and from five to six miles in length. The geology of this district and the occurrence of emery in it might be described in almost the same language as that which Dr. Smith applies to the celebrated emery district near Ephesus in Asia Minor.

Dr. Smith* says "all the rocks of the surrounding country appear to belong to the old series; the limestone is entirely devoid of fossils and metamorphic in character; it rests on the older schists of which mica schist appears the most abundant; and this again farther to the north was traced in contact with gneiss. The limestone is of a light blue passing into coarse-grained marble." "The place, however, to which it is traced in greatest abundance, is on a part of the summit about three miles from the village of Gumuch, and some 1,500 to 2,000 feet above the level of the valley; it overlooks the magnificent plain of the Miandre, whose curiously tortuous course is seen as if traced on a map. The emery lies scattered on the surface * * * in angular fragments of a dark color, and large masses of several tons weight are seen projecting above the surface; in penetrating the soil, the emery is found embedded in it and a little further down it is come to in the rock." "Some times the emery forms a solid mass several yards in length and breadth."

In describing the Westchester County emery beds, we would say that the place in which the largest number of openings have been made, and which has excited the most interest, is on a part of the summit about three miles from

* *Am. Jour. Sci. and Arts.* **2**, x, 356.

the town of Peekskill, and about 700 to 800 feet above tide level. It overlooks on the one side, the valley of the Croton, whose stream is invisible, and on the other side, the Hudson, whose distant waters look like some lake in a painting. On the north and northeast of the emery belt are outcrops of granite. South of it lies the common marble of Sing Sing—still further south, at Spuyten Duyvil, occur the oldest of the Laurentian gneisses, and still further south, on Manhattan Island, the mica schist. The emery is, however, all immediately associated with a hornblende rock. Large masses of emery are seen projecting above the surface. These are delusive, and those which hold out a large promise are sometimes found to extend only one or two feet underground and to yield only five to twenty tons. Such masses are usually surrounded by soft, reddish earth.

Dr. Smith says of the Turkish locality, "the earth in the neighborhood of the blocks of emery is almost always of a red color, and serves as an indication to those who are in search of the mineral." In Westchester, the red earth is not an indication, for there is within the emery belt an iron-bearing rock which decomposes very rapidly and forms a red earth, while there is no emery associated with it. There is no sign of fracture in these discontinuous masses of moderate size, and they occur on the very tops of hills and under such circumstances as to indicate that they are not boulders and have not broken down from higher cliffs. As in Turkey, so also here, "in penetrating the soil, the emery is found embedded in it, and a little further down it is come to in the rock." Small fragments turned up by the plow in cultivated fields are sometimes the first indications. Search in their neighborhood reveals other fragments embedded in the earth, and near these and lower is found the rock. Sometimes this only approaches the surface and forms such a small point that it might lie undiscovered for years. In one place discovery on the surface of a very fine grained, pure block, weighing about 200 pounds, stimulated search which was continued at intervals, fruitlessly, for several years. Other varieties were discovered, but no sample like the original. Several blasts were made within a few feet of the nar-

row point which just fell short of reaching the surface, and yet did not disclose it. A lucky blast uncovered it, and over 100 tons of uniform quality were taken out, leaving it far from exhausted. As in Turkey, so also here, "the emery lies scattered on the surface * * * in angular fragments of a dark color," but at this point my description must differ from that of Dr. Smith.. He says: "in no place does it present anything like a vein, nor has it signs of stratification." I find, in Westchester, that the angular pieces generally indicate veins. Such veins are distinct and numerous. The regularity with which they thin out at the edges and thicken at the centre suggests true lenticular beds, though there are, of course, exceptions to the rule. The quite regular recurrence of seams separated, but parallel, strongly suggests stratification. These seams occur in the solid rock and the emery breaks freely from it, it being a most unusual thing to find any adherence of the top or bed rock.

Emery from veins breaks easily, with flat sides and sharp angles. These sides, when dry, often seem painted, so bright are they with yellow and red, and sometimes they take on an almost iridescent tint, with sheen of pink and green. Strangely enough, large amorphous masses are sometimes found, disconnected from rock, and lying between the regular veins. These amorphous masses, whether they be small or large, present no angular outlines, and do not break up in such flat-sided pieces as do the seams. It should be noted that the angularity of the vein emery is not due to its being freshly mined. The broken-down edges of veins, found in fragments on the hill-sides far below the veins, and which have weathered for hundreds or thousands of years, seem as sharp and unaltered as those freshly broken. The amorphous masses, on the other hand, are so destitute of cleavage that continued use of a heavy sledge hammer only batters them into shapeless pieces. The emery in each vein is of comparatively uniform quality though differences can sometimes be detected in blocks lying side by side. That in the amorphous masses varies far more. One such mass, of yet unascertained quality, I

estimate, by a rough calculation of its cubic contents, to contain from 500 to 700 tons. This mass was jokingly christened by the miners as "Knight's bonanza." It was of a light grayish color, not markedly different from the top and bed rock, from which it stood out almost separately on all sides, and like those rocks, was covered with gray moss. The owner decided that all the rock was alike and estimated that there were hundreds of thousands of tons.

The emery of this district presents easily discernible differences. Some is coarse grained, some fine, some black and shiny, some gray. Some is uniform in color, some distinctly streaked.

This deposit was described about twenty years ago by Dr. J. P. Kimball, and his classification agrees with my own. He describes two classes as "granular, massive, resinous," giving a slightly different analysis for each. I should say one coarse and one fine. A third he describes as a "banded variety, gray in general color, and sparkling, from the presence of a micaceous mineral." A fourth, as a "quartzose variety, gray and sparkling, like number three but without a banded or gneissic structure."

Inasmuch as the "Emery Manufacturers' Association" has issued a circular referring to the product of these mines as "a spurious article of emery," and referring to its ore as "inferior or comparatively worthless stone," the opinion of Dr. Kimball is worth consideration. It deserves additional weight because his investigation had no reference whatever to the use of this ore as an abrasive. It was solely with the view of its use in iron metallurgy that his study was made. The analyses he refers to were made by Dr. C. F. Chandler and Mr. F. A. Cairns. Dr. Kimball says, "The above analyses, together with the physical and mineralogical features of this material, serve to identify its character as a mixture of corundum with magnetite, slightly titaniferous, as usual, when thus associated, analogous to the emery of Chester, Mass., and its proportions bearing a still closer resemblance to specimens obtained by Dr. Genth, from the Goldboro ore belt of North Carolina in 1871, and analyzed by that chemist." Dr. Kimball's article is entitled

"Emery and its Uses in Iron Metallurgy," and throughout this lengthened essay he always refers to the Westchester ores as emery. It is an admitted fact that the percentage of alumina in these ores is less than that in the Greek and Turkish samples analyzed by Dr. Smith, but I have already shown that the effective hardness of Dr. Smith's samples was not proportioned to the percentage of alumina. I have also shown that American corundum has been sold at the highest price commanded by a genuine article, though its percentage of alumina was much less than that contained in the Westchester ores, and though it contained no insoluble corundum at all. In fact, Dr. Chatard* says of it that "the sample contained in all probability no corun-

* The six analyses of Dr. Chatard referred to in this lecture were made at my request, and were from samples of commercial material. These samples were reduced to such fine powder that their identity was destroyed. With their origin unknown and their superficial characteristics obscured, Dr. Chatard, from chemical analysis alone, pronounces one sample of commercial corundum (southern) to be from a non-corundum-bearing rock and having no insoluble corundum at all. The sample of Westchester emery, which contained 10·14 of insoluble corundum, he classed as spinel.

As bearing strongly on popular beliefs as to the differences between imported and domestic emery, it is worth while to sum up the opinions of distinguished scientific men as to the identity and characters of various emeries.

Dr. Charles T. Jackson* gives analyses showing that the proportions of alumina and iron in Chester, Mass., emery agree closely with those of Naxos emery, and states that practical trial in armories and machine shops proved the Chester emery fully equal to the Naxos. Dr. J. Lawrence Smith† states that he considers "the Chester mineral as true an emery as that of Naxos." Dr. J. P. Kimball‡ states that the analyses of Westchester emery identify it "as a mixture of corundum with magnetite analogous to the emery of Chester." Dr. Smith‖ confirms Dr. Chatard's recent identification of Westchester emery with spinel by pronouncing all emery spinel. In commenting on the discussion of Professors Jackson and Shepard, as to whether emery was a granular variety of corundum or a separate species, Dr. Smith says: "the question as to the mineralogical position of emery can be easily settled without resorting to any new mineral species. It is simply a massive iron spinel (hercynite) with the anomaly of having a hardness equal to corundum."

* *Am. Jour. Sci. and Arts.* 2, xxxix, 50.
† *Am. Jour. Sci. and Arts.* 2, xlii, 89
‡ *Am. Chemist*, date unknown; republished in *The Emery Grinder*. April, 1874.
‖ *Am. Jour. Sci. and Arts.* 2, xlii, 83.

dum at all, being only an ordinary silicate." It was so much of a silicate that it contained 44·64 per cent. of silica, while the largest percentage in any sample of emery analyzed by Drs. Smith and Chatard was only 9·63 per cent.

Having shown that the chemical proportions of emery and corundum bear no direct ratio to price or effective hardness, we have now to consider whether there is a direct relation between effective hardness and abrasive value. In his article on "Mineralogy" in the *Encyclopædia Britannica*, Prof. M. F. Heddle distinguishes two forms of hardness. He explains the established scale of hardness which culminates in the diamond, and shows how the file test is applied. But he then goes on to show that minerals may appear soft under the file test while they scratch other minerals on which the file has no effect. This he says is because the particles are hard but loosely aggregated. Dr. Smith, also, dwells upon this point. He says that his glass and agate test for abrasive effect does not furnish the mineralogical hardness,* "two minerals possessing the same hardness but differing in structure, one being friable, and the other resisting, will be found very different in their abrasive effects." The inference which Dr. Smith draws is against the friable and in favor of the resisting material. This inference is perfectly correct so far as it relates to the exact method by which Dr. Smith secured his result, or in so far as it may relate to practical processes which reproduce Dr. Smith's conditions. It is utterly inaccurate and misleading so far as it refers to the larger proportion of modern processes in which abrasives are used. I am inclined to think that Dr. Smith's test for effective hardness by use of glass and agate is responsible for the almost hopeless confusion which exists to-day regarding the requisites of a good abrasive. The general inference is that hardness is the prime requisite.

Practical operations in emery mining prove that this inference is a mistaken one. It is no uncommon thing to find the rock overlying an emery vein harder than the

* *Amer. Jour. Sci. and Arts.* 2, x, 363.

emery. That is to say, it is more resisting to the action of a drill, dulling the tool more rapidly and demanding more time to drill an equal distance. If the class of hardness shown by this rock were the right kind, it ought to make a good abrasive, but actual trial shows that it does not do so. Its hardness is probably due to its compact aggregation.

In Dr. Smith's famous test, which has been copied by all his followers, separate grains of emery, not bound to each other or to anything else, but rolling and moving freely, are rubbed between two pieces of glass or between glass and agate. If these grains are loosely aggregated or if they are of bad shape (for instance, flat and thin, with splintery edges), they will, being unsupported, crush down rapidly between the hard opposing surfaces, while fragments of diamond or sapphire would stand up larger and do more work.

The practical question, however, is, how many modern processes reproduce Dr. Smith's test conditions. Emery is principally used on wood and leather wheels, in solid wheels and in the form of emery cloth or paper. It is also used on the lapidary's wheel. If the latter is a lead wheel the emery becomes embedded in the lead, the lead being selected because it is soft enough to allow of the emery grains sinking into it, and so being supported and backed up. When used on the wood and leather wheel emery is attached to the leather band by a coat of the strongest, toughest glue. The emery is forced into the hot, plastic glue, which fills all interstices in the grain, adapts itself to every peculiarity of shape, and then hardens into a perfectly fitted bed or backing which supports and braces the grain. When used in solid wheels emery is still more thoroughly braced and backed up, for it is first mixed with a base and then united with such base by gums, glues or cements, aided by the processes of slow drying, baking heat, vitrifaction, tamping and hydraulic pressure. When emery is used to make emery cloth and paper it is also bedded in and backed up by glue.

In not one of these cases do the emery grains have any free motion of their own. They do not change place in

relation to each other, and are not worn-out by the friction of emery with emery. They do not break down and crush to pieces, for they are not only backed but surrounded by their protecting matrix, and so cannot flatten, spread and squeeze apart as does a free, unsupported grain of which only a small part comes in contact with the opposing surfaces. Still another vital condition of Dr. Smith's test is lacking in the cases of the lead wheel, the leather-covered wheel, and the emery cloth and paper. In these cases the emery is not rubbed between two unyielding surfaces, such as glass and agate, but between one yielding and one unyielding. Before the grain can crush, the leather, generally chosen for its sponginess and compressibility, will yield—the lead will allow the grain to sink deeper in its surface, the cloth and paper will do the same. These latter, so thin as to possess little compressibility, are often backed up by the human hand, which affords the same cushion as does the spongy walrus or sea-horse.

Of these differences in the conditions of use the ordinary buyer takes no more note than does the professional expert. He applies, in a rough way, the same sort of test as does the expert—a test which only shows what the emery will do under conditions entirely different from those in which it will be used. He placed some of the emery on a smooth, solid piece of metal, and presses it as hard as he can, and with a sliding motion, with another piece of metal. If the grains are loosely aggregated or badly shaped they crush to pieces and the emery is condemned. Another test is to place the emery in the palm of the hand and rub it together with the thumb or finger. Here the emery is used as an abrasive agent to destroy itself. The thin edges and sharp corners are ground off and the emery is condemned as soft and dirty.

It appears, therefore, that looseness of aggregation, or friability, and also the shape of grain, may be of importance. It is in the larger grains that friability shows most markedly, and it is quite probable that this friability differs very greatly in grains of different size. If emery is a varied mechanical mixture minute subdivision may lessen the

variety of materials in each grain and so alter the standard of cohesion and aggregation. Where the grain, in crushing down, sets free particles of pure sapphire, it seems clear that these will not crush to pieces as the more heterogeneous grain did. Even if a coarse grain were proved too friable for some special work it would not follow that finer emery from the same ore was also too friable. It is an important fact that the proportion of coarse grain in use has greatly diminished and that few processes really demand a very coarse and a very resisting grain. The manufacturers of plows and of fire-proof safes, and the workers in granite are those who seem most inclined to coarse emery. The coarser it is the more resistant must be the grain, for the more it projects beyond its glue bed the more easily will it break off or crush down. It is an interesting fact that emery which is pronounced too soft for such use may be adapted to it by special processes. Whatever machine or process may be used to accomplish this, the principle of its operation is to abrade the emery by friction against itself till sharp points, brittle corners and loosely adhering particles are removed.

Concerning the comparative values of round-grained emery and that of other shapes much difference of opinion exists. The rounded or cubical grain of large size will certainly be most resistant, and, in all processes which reproduce the conditions of Dr. Smith's test, will probably be most valuable; but it does not seem evident that any advantage will attach to such shapes when they are embedded in a solid mass. A rounded or cubical grain of the finest grained, hardest and most compact ore would probably be the best for granite workers, because their processes are such as to crush a friable grain. It is this fact which has led to the growth of a new industry in the manufacture of artificial abrasives. Chilled shot and crushed steel have already won a position among stone workers and will probably have lasting and increasing sale.*

* The makers of crushed steel report that in 1890, their first business year, they sold 230,000 pounds, which sale increased in 1892 to 460,000 pounds. I have not been able to learn the annual product of chilled shot.

A chilled shot and a grain of Westchester emery, loosely aggregated and bristling with points, afford extreme contrasts. Our facts lead to the belief that loose aggregation is not a serious defect, provided, as Dr. Heddle shows, that the particles are hard enough. The inference from his statement is that abrasive effect is proportioned to the hardness of the particles. But Dr. Heddle's file test, like the glass and agate test of Dr. Smith, lacks the principal condition in the modern use of abrasives. That condition is high speed. Penetration is effected by velocity, and abrasion is effected by the points of one substance penetrating the substance of another. A board is harder than a candle, yet it is said that a candle can be shot through a board. Glass is harder than lead, yet a bullet of lead will make a clean hole through a window. It seems possible that a like rule may hold good as to abrasives, and that mineral grains may, if used at the right velocity, penetrate substances harder than themselves and prove satisfactory agents of abrasion.

On still another important point does Dr. Smith's test fail to meet the requirements of practical use. It takes no note of the pressure required. If a grain of crushed steel or a diamond gem be embedded in the face of a solid emery wheel these two articles would abrade through the use of whatever projecting points they might present. As the points wear off flat faces would appear, destitute of cutting power, and no further abrasion would take place until pressure enough had been applied to crush the grains of diamond and steel and manufacture new points for them. The harder and more resistant the grains were the greater would be the pressure needed to effect this. The criterion which demands the extreme of hardness, fineness, purity, compactness and resistance in abrading minerals, is one which calls on the manufacturer for a wasteful expenditure of power, which forces on the laborer undue physical strain, which prevents his attainment of manual skill, and which exposes him to unnecessary danger. This criterion has made durability the prime requisite in abrading materials and tools—a durability which the buyer demands without

reference to the cost of his product, or to the welfare and safety of his men.

Resistance of material calls for resistance of worker, and that abrading material is best which does equal work in equal time with the least possible power and pressure. Such adaptation to its work is not likely to be found in any mineral of extreme purity or oneness of composition, whose texture is dense, whose grain is fine, whose cohesion is great. It is more likely to be found in a mineral of such friability and such varied composition as causes it to break up into changing and irregular forms under moderate pressure.

While I consider the facts thus far stated unquestionable and the inferences from them correct, I have to avow regarding emery and other abrasives, what I avowed as to emery wheels some four years ago, before the members of this Institute, namely, that there are few exact data to demonstrate my inferences. The greater the consumption of abrasives and the more varied their use, the greater is the divergence of opinions—the more hopeless the confusion—the deeper the distrust as to any scientific basis in the grinding industry. The men who employ licensed firemen to run a steam boiler, and still further protect themselves by the periodical test of their boilers, give no thought to the latent explosibility of solid emery wheels in charge of common laborers. The railroad, which sends in to the founder its own chemical formula for car brasses, pays no heed to the inherent safety of a vulcanized emery wheel or the inherent danger of a vitrified one. The manufacturer who insists on having the candle-power of his electric light guaranteed, and the horse-power of his turbine or engine measured by a dynamometer, buys the lowest-priced emery wheel he can find, but never discovers the cost of that wheel's product.

This degradation of the grinding industry is due in part to that criterion of hardness in abrasive material which has made weight and strength the criterion of the human grinder. It is due in part to the fact that grinding problems are so obscure and difficult to the skilled mechanic that he remits them unsolved to the unlearned workman. This

degradation of the grinding industry goes back to early times. In the Royal Museum at Berlin is a painting by Gerard Ter Borch, of Deventer, probably executed about 1650, which is marked by all that detail which generally characterizes painting of the Holland school. This picture represents "The Grinder's Family." The work-room is a tumble-down, wretched shed, attached to the dwelling-house. Only one member of the family is at work, unless that operation can be called work in which the mother is engaged. She seems to be searching in the hair of her young daughter for something that ought not to be there. The grown son, with almost a simpleton's face, and with tattered garments, leans idly against a post. The old father has a wide shelf, just level with the top of the grindstone, and lies upon it at full length upon his stomach, while he presses a scythe upon the grindstone. The other scythes lie out of reach on the floor. The mandril of the stone revolves in an uncovered groove in a beam, and a notch in that beam holds a wooden wedge to keep the mandril in its place. Everything indicates that activity is at a big discount—art at a low ebb and wages lower still.

It is unfair, you will say, to steal this quarter-century old example from a pastoral country like Holland. Why not go to a manufacturing country in modern times? Why not visit Sheffield, for instance? I did visit Sheffield in 1892. I asked a master cutler to show me the latest thing in grinding. He said there was no late thing. I asked him about abrasives and he said each individual grinder supplied his own, buying a few pennysworth of emery at the nearest chemist's and having it chalked up against him just as he had his beer chalked up at the tavern. He said the grinders could generally be found at work when they had no money to spend, always providing there wasn't a football match on hand. He told me to visit Rodgers' and see what they did and then he would take me outside the town to mills hundreds of years old and that I would find the tools, the processes, the conditions identical. The factory building he called "a wheel," and the vaulted dungeons, whose windows had all their glass shattered to let in the

light which the splash and slop of the wet stone obscured, he called "troughs." A strap (belt), a stone, a razor and a grinder were what constituted the grinding industry. I ignorantly spoke of the grinders as "men," but he said it was a common Sheffield saying, "he's not a man; he's only a grinder." I did go to the main establishment of Rodgers and then to a "wheel" in a valley some miles out of the city. The "wheel" was a long, dull building of cut stone. The newer part was about 100 or 150 years old, while one wing was much older—too old for the date of its founding to be remembered. The grinder was a man over sixty, and he assured me that his father and his father's father had also ground razors there. As I talked with him two younger men examined a pile of apparently worn-out grindstones, which they said were bought second-hand, when too small for other use, and, selecting one of the quality desired, split it in two pieces because it was too thick. From this dilapidated building, from these scant tools and crude processes, were evolved by grinders not thought worthy to be called men, those blades which have made the name of Rodgers famous. Inherited skill and restriction to one narrow branch of work take the place of modern improvements. As I remember this initiation into the art of Sheffield, I smile at the London merchant who wrote to America that he could get a big order for Japan if I could supply a complete plant for razor grinding.

In our own freer and more versatile country the tyranny of the trades-union has not gone so far as to insist that only the sons and grandsons of razor grinders shall learn to grind razors. Instead of old processes, perpetuated unchanged for hundreds of years, we have all the newest wrinkles. Automatic grinding machines, almost human in their complication, and which render brains almost unnecessary to the workman; and others which look beautifully on paper, and either go to the waste pile or swell the maker's account of "returned goods." We have the newest wrinkles, but no rules—the most ingenious devices, but no accepted standards—the most varied opinions, but no authorities.

While grinding processes are complicated and solid emery wheels high-class tools, and while economical grinding demands conditions based on the careful study of educated mechanics, no one establishment uses enough to enlist the interest of the educated man. Abrasives are committed to the lowest class of labor, and reports as to results drift through circuitous channels to the buyer, whose next purchase is based on the latest and most distorted report. The name of "Wellington" is so potent that often the grinder will use no other brand of emery, though he will take any and all kinds of material without discovering any difference, provided they are poured out of a "Wellington" keg and have a color not found in the original material.

Throughout the apparent discussiveness of this lecture I have carried on a sustained argument, but that argument has been so lengthy and so involved as to demand a summary of conclusions.

It seems clear to me that current opinions about abrasives have been based too much on cabinet specimens and laboratory experiments, and too little on the average products of the mine and on the conditions of modern work. It seems demonstrated that chemical analysis does not gauge accurately the abrasive capacity of any mineral—that the hardness of such material does not bear a definite relation to its purity (meaning thereby a high percentage of alumina), and equally clear that mere hardness is not the prime requisite. It seems clear that abrasive capacity depends largely on some unexplained peculiarity of structure. It seems evident that speed, time and pressure are factors too little considered in connection with the problem of safe and economical grinding. It seems settled that external appearance is a poor guide to grinding capacity; that colors, shape of grain and attractability by the magnet are not trustworthy indications. It seems clear that commercial abrasives vary in quality, and that their acceptance or condemnation depends on prejudices and notions rather than on ascertained facts as to cost of product.

Some of the causes which lead to variable and contradictory results with abrasives are those common to shop prac-

tice, but which produce far greater effects with the emery wheel than with the lathe or planer. The effective work of an emery wheel is based on its speed of a mile a minute. The correct speed is less likely to be maintained, because the pressure against the wheel is heavier and more variable than that in a lathe. The lathe tool presses with a sharp point only against the revolving work, and is so set that, after the first cut, the pressure scarcely changes.

The grinder, however, forces his work against the wheel with greatly varying strength, and sometimes adds to direct pressure a heavy leverage. I have often seen wheels slowed down till they almost stopped. Pulleys of too small diameters are used, and belts which are too narrow. Slip of belt and diminution of speed are potent factors in the problem.

Another equally potent one is discontinuity of contact. A wheel may run a mile a minute and yet be so out of round or mounted on such a light machine or shaky floor that vibration and chatter interfere with continuous contact. Instead of a mile long file passing over the work in a minute, it is sometimes only an eighth or a quarter mile file. I have examined wheels whose continuous stream of sparks suggested continuous contact, and found that only two or three inches of the surface had come in contact with the metal. The custom of imputing all variability of result to defect in the wheel and the overlooking of variability in the metal operated on is another cause of contradictory result. A class of wheels which had long suited a plow manufacturer was at last repeatedly condemned and the wheel declared worthless. After a very long interval it appeared that the plows had been changed from one homogeneous thickness to three sheets of varying temper. A class of wheels was condemned which had long suited for car brasses, and only after long delay was it made known that the first metal was yellow brass and the last phosphor-bronze. I have lately discovered by use of an improved testing machine that the quality of the test bars of cast iron is more variable than the quality of tanite wheels.

What, then, is needed, to clear up this confusion?

It seems to me that the thing most needed is a practical testing machine, which shall take the place of the laboratory test made popular by Dr. J. Lawrence Smith. Such a machine should be run by an independent engine to secure uniform speed. Pulleys and belts should be so proportioned that no slip shall occur. Floor and machine should be so solid as to do away with vibration. Test bars should be employed of the most uniform quality. And then a series of experiments should be carried out so as to establish definite standards. It should be ascertained what is the least pressure per square inch at which a cubic inch of test metal can be ground off in the least time with the least consumption of wheel material. In other words, the final economy of the process should be demonstrated, taking into strict account the consumption of wheel material, the amount of metal ground, the time occupied, the speed employed, the horse-power expended and the pressure exerted. Thus will gradually arise a fixed standard as to what constitutes a good emery wheel, and the buyer will demand an article of known and certified productive effect whose cost of product is also known. Thus will arise on the grinder's side a demand for those wheels and those abrasives which entail the least bodily fatigue. Thus will arise a public opinion which shall hold to strict account those reckless buyers who put wheels of known dangerous quality in the hands of their employés. For this machine should not only be used to ascertain the economic value of abrasives, but also to demonstrate the relative safety of solid emery wheels.

In closing this lecture, I desire to point out that it is not so much a statement of what is known about abrasives as a confession of how little is known. This confession imputes no special ignorance to the user, but pleads the great obscurity of the problem. I believe the difference between the poorest and the best of the abrasives in common use is so moderate that great expertness is required to discover it.

My object will be accomplished if, by pointing out the fallacies which attach to old-time tests and superficial indi-

cations, the way is cleared for a more scientific method of ascertaining abrasive quality—a more business-like way of getting at the economic result—and a more humane consideration of the laborer's danger and fatigue.

APPLICATION OF THE METHOD OF LEAST SQUARES TO THE DEVELOPMENT OF FUNCTIONS.

By F. Gilman.

The usual methods of developing a function are by the binomial series and by the theorems of Maclaurin and Taylor. In general practice, however, only a limited number of terms of the development can be calculated, and for such cases these theorems do not give the best values obtainable for the coëfficients.

Let us take, for example, the function

$$\frac{1}{\sqrt{1+x}}$$

The binomial theorem gives

$$\frac{1}{\sqrt{1+x}} = 1 - \tfrac{1}{2}x + \tfrac{3}{8}x^2 - \tfrac{5}{16}x^3 + \qquad (1)$$

We will now assume

$$\frac{1}{\sqrt{1+x}} = 1 + ax + bx^2 + cx^3$$

and treating

$$\frac{1}{\sqrt{1+x}}$$

as an observed quantity, we will determine the values of the constants a, b and c from the condition that the sum of the squares of the residual errors shall be a minimum.

Supposing x to vary from 0 to 1, the following table gives the values of

$$\frac{1}{\sqrt{1+x}}$$

corresponding to different values of x:

x	$\frac{1}{\sqrt{1+x}}$
·0	1·0000
·1	·9535
·2	·9129
·3	·8771
·4	·8452
·5	·8165
·6	·7906
·7	·7670
·8	·7454
·9	·7255
1·0	·7071

Hence, for the first equation of condition, we have

$$1 + a\,(0{\cdot}1) + b\,(0{\cdot}01) + c\,(0{\cdot}001) = 0{\cdot}9535$$

or

$$a\,(0{\cdot}1) + b\,(0{\cdot}01) + c\,(0{\cdot}001) + 0{\cdot}0465 = 0$$

Hence, the ten equations of condition may be written in the following form:

a	b	c	l
+ 0·1	+ 0·01	+ 0·001	+ 0·0465
·2	·04	·008	·0871
·3	·09	·027	·1229
·4	·16	·064	·1548
·5	·25	·125	·1835
·6	·36	·216	·2094
·7	·49	·343	·2330
·8	·64	·512	·2546
·9	·81	·729	·2745
1·0	1·00	1·000	·2929

The normal equations are readily formed from these, and are as follows:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,l]$
+ 3·85	+ 3·025	+ 2·5333	+ 1·24488
	+ 2·5333	+ 2·20825	+ 0·95330
		+ 1·97840	+ 0·78532

The solution of these equations give

$$a = -0{\cdot}486$$
$$b = +0{\cdot}281$$
$$c = -0{\cdot}088$$

Hence, we have the following expression for the development

$$\frac{1}{\sqrt{1+x}} = 1 - 0{\cdot}486\,x + 0{\cdot}281\,x^2 - 0{\cdot}088\,x^3 \qquad (2)$$

The following table shows a comparison of the results of this development with that given by the binomial series having the same number of terms:

x	$\frac{1}{\sqrt{1+x}}$	$\frac{1}{\sqrt{1+x}}$ *by equation* (1)	$\frac{1}{\sqrt{1+x}}$ *by equation* (2)
·0	1·0000	1·0000	1·0000
·1	·9535	·9534	·9541
·2	·9129	·9125	·9133
·3	·8771	·8753	·8771
·4	·8452	·8400	·8449
·5	·8165	·8047	·8162
·6	·7906	·7675	·7906
·7	·7670	·7265	·7673
·8	·7454	·6800	·7460
·9	·7255	·6259	·7261
1·0	·7071	·5625	·7070

It is readily seen by comparing the third and fourth columns of this table with the second (the second representing the true value of the function) that the binomial development is very inferior in accuracy to the development given by equation (2), and which may be called the least square development. For some very small values of x, as 0·1, the results of the least square development are not quite as accurate as those of the binomial development; but even this small difference might be made to disappear by a proper system of weighting the condition equations.

Some, however, may object to the conclusiveness of the preceding table, on the ground that it does not give a fair comparison, since it is restricted to those values of the function which were used in forming the condition equations, and that the least square development might not be expected to give nearly as correct results for intermediate values of the function.

In order to anticipate this objection, I give the following

table of results, calculated for values of x intermediate to those given in the preceding table:

x	$\frac{1}{\sqrt{1+x}}$	$\frac{1}{\sqrt{1+x}}$ by equation (1)	$\frac{1}{\sqrt{1+x}}$ by equation (2)
0·05	0·9759	0·9759	0·9764
·15	·9325	·9324	·9331
·25	·8944	·8936	·8947
·35	·8607	·8575	·8605
·45	·8305	·8225	·8302
·55	·8032	·7864	·8031
·65	·7785	·7476	·7787
·75	·7559	·7041	·7564
·85	·7352	·6540	·7359
·95	·7161	·5955	·7164

It appears, from the above table, that the accuracy of the least square development is practically the same for these intermediate values of x as it was for those values by means of which it was determined. It follows from this that the accuracy of the development would not have been materially increased by increasing the number of equations of condition.

As a further test of its accuracy we may apply it to the determination of the definite integral,

$$\int_0^1 \frac{dx}{\sqrt{1+x}}$$

the numerical value of which is known to be 0·8284.

Multiplying the least square development of

$$\frac{1}{\sqrt{1+x}}$$

by dx and integrating between the limits 0 and 1, we obtain for the numerical value of the integral 0·8287, which is in error by less than one-twenty-fifth of one per cent. The value of this integral, obtained by using the binomial series with the same number of terms, is 0·7969, which is nearly four per cent. in error.

Take next the definite integral

$$\int_0^1 \frac{dx}{\sqrt{1+x^2}} = 0{\cdot}8814$$

The least square development gives:

$$\frac{1}{\sqrt{1+x^3}} = 1 - .486\,x^3 + .281\,x^4 - .088\,x^6$$

Multiplying this development by dx and integrating between the limits 0 and 1, we obtain for the value of the integral 0·8816, which is in error by one-fiftieth of one per cent. Using the binomial series with the same number of terms, we obtain 0·8637 for the integral, which is two per cent. in error.

Finally, let it be required to find the definite integral

$$\int_0^{10} \frac{dx}{\sqrt{1+x}}$$

the value of which is known to be 4·6332.

We first integrate between the limits 0 and 1, and find as before that the integral is 0·8287. We next integrate between the limits 1 and 10.

In order to do this we write the function in a different form, as follows:

$$\frac{1}{\sqrt{1+x}} = \frac{1}{\sqrt{x}\,\sqrt{1+\frac{1}{x}}}$$

$$\frac{1}{\sqrt{1+\frac{1}{x}}} = 1 - \frac{.486}{x} + \frac{.281}{x^2} - \frac{.088}{x^3}$$

$$\frac{1}{\sqrt{1+x}} = \frac{1}{\sqrt{x}} - \frac{.486}{x^{\frac{3}{2}}} + \frac{.281}{x^{\frac{5}{2}}} - \frac{.088}{x^{\frac{7}{2}}}$$

$$\int \frac{dx}{\sqrt{1+x}} = 2\sqrt{x} + \frac{.972}{x^{\frac{1}{2}}} - \frac{.1874}{x^{\frac{3}{2}}} + \frac{.0352}{x^{\frac{5}{2}}}$$

Taking this between the limits 1 and 10, we obtain 3·8063, and adding to this 0·8287, we obtain for the integral 4·6350, which is in error by less than one-twentieth of one per cent.

The value of the integral obtained by using the binomial series with the same number of terms is 4·5552, which is nearly two per cent. in error. It is evident from the pre-

ceding examples that the expression given by least squares for the function

$$\frac{1}{\sqrt{1+x}}$$

will enable us to determine the definite integral of any function of the form

$$\frac{a\,dx}{\sqrt{b+cx^n}}$$

with an accuracy far superior to that obtained by using the binomial series for the development.

As an additional example take the more complex function

$$\frac{1}{\sqrt{1+x+x^2+x^3+x^4}}$$

in which x is supposed to vary from 0 to 1; for if x were greater than 1, the function could be transformed into another of the same kind, by putting

$$x = \frac{1}{z}$$

z being the new variable.

By the method of least squares we find exactly as in the preceding case

$$\frac{1}{\sqrt{1+x+x^2+x^3+x^4}} = 1 + ax + bx^2 + cx^3$$

in which

$$a = -0{\cdot}47189$$
$$b = -0{\cdot}28755$$
$$c = +0{\cdot}20771$$

The development of this function, according to Maclaurin's theorem, gives the following values for the coëfficients:

$$a = -\tfrac{1}{2}$$
$$b = -\tfrac{1}{8}$$
$$c = -\tfrac{1}{16}$$

The table below shows the comparative accuracy of the two methods of development, the numbers in the second column being the true values of the function.

$$\frac{1}{\sqrt{1 + x + x^2 + x^3 + x^4}} = f(x)$$

x	$f(x)$	$f(x)$ *by least square development.*	$f(x)$ *by Maclaurin's development.*
0·0	1·0000	1·0000	1·0000
·1	0·9487	0·9501	0·9486
·2	·8946	0·8958	0·8945
·3	·8377	·8382	0·8370
·4	·7786	·7786	·7760
·5	·7184	·7182	·7109
·6	·6586	·6583	·6415
·7	·6005	·6001	·5673
·8	·5454	·5448	·4880
·9	·4942	·4938	·4032
1·0	·4472	·4483	·3125

ENGINEERING PRACTICE AND EDUCATION.

By Gaetano Lanza, S. B., C. & M. E.,
Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

[*Continued from p. 394.*]

In the infancy of any new industry questions of the proper strength of the machinery, and of adopting such arrangements as shall insure economical operation, are very likely to be neglected; the main efforts of the promoters being generally directed towards making the machines work at all; and if economy is lacking, the only result is that the prices of the products are put at such a figure as to cover the expenses and provide a good profit. Then there is a strong tendency, as long as the companies can make money as fast as they desire, without attending to matters of economy, to disregard them; and if they make any attempts to increase their income, it is rather by an increase of the plant than by introducing more economical working into

what they already have. Hence it is that in the early stages of an industry, there is usually less engineering and less scientific work done than later, for scientific work is precisely what is needed to produce economy. But after the industry has been carried on for a long time by a number of people, and competition has become rife, then those who are at the head of it find themselves forced to consider questions that affect the economical working of their industry, for on the proper solution of these questions depends success or failure. It follows, therefore, that in an industrial country like our own, there is more and more demand for scientific work, and, hence, more and more demand for engineering work. I might cite a great many cases to illustrate this matter, but one of the most marked, perhaps, is that of making illuminating gas, where it has been the fact until very recently that so much money could be made anyway, that the gas manufacturers did not care to take pains to avoid waste, and very little, if any, effort was made to economize, and hardly any attempt to operate the works on sound engineering principles.

But I am digressing from my subject. Coming back then to the locomotive, let us see how the remarks I have been making apply to that. In introducing the locomotive into American practice, it became at once evident that the rigidity with which locomotives were being built in Europe was not suited for travel on roads such as we could afford to build at the time, nor for those containing as sharp, curves as it was, and still is, frequently desirable to make. Hence, to the credit of American genius be it said that our railroad men at once proceeded to introduce the modifications necessary to render the locomotive a more flexible machine, which would stay on the track, even if the latter were uneven, and if the curves were sharp and which should be so easily accessible in all its parts and so simple in construction that it could be easily repaired. Moreover, the modifications introduced by American inventive genius, were good features, even after the country developed so that we could have better permanent way, and some of these points are of such decided advantage that we find more and

more tendency to imitate them, on the part of our neighbors across the ocean, in their most modern constructions.

Now, these efforts might be said to have been attempts to make the machine work at all, and there was too much tendency to determine the question of strength of the parts by what was and is sometimes called practical experience, *i. e.*, by waiting till something broke before pronouncing it too weak, and then making it larger, *i. e.*, putting in more iron in subsequent constructions.

To illustrate the fallacy of such a course by a very extreme case, I may say that, in the early days of locomotive practice, parallel rods were sometimes made of circular section, and that as soon as the speeds became at all considerable, such rods were almost sure to break. Now, suppose the course outlined above were followed and a larger rod of circular section substituted in subsequent construc tions. Any one at all familiar with the scientific principles at the foundation of the theory of the way in which a beam resists a transverse load, could easily predict the result, which is that the new one would be practically no stronger than the old one, while weighing more; for, as soon as the speed of the locomotive is at all considerable, the transverse load, due to the action of centrifugal force on the parallel rod, forms by far the greater part of the load that it has to sustain, and by the course adopted this load would have been increased in the same proportion as the power of resistance of the rod. A little figuring in such cases would save a great deal of costly experience, and often a number of accidents. Of course, railroad men know better now than to use round parallel rods, but there is not care enough taken yet in calculating the strength and stiff. ness of all the diiferent parts of locomotives.

Turning, now, from questions that involve the strength of materials to those that involve economy, we find that fuel, both wood and coal, has been so easily and so cheaply obtained heretofore that railroad men paid little or no attention to this matter; and while I do not believe that the locomotive is as wasteful of fuel as is frequently imagined, nevertheless, hardly any really serious efforts

were formerly made to ascertain and develop means for reducing the coal consumption, such as have been made constantly in the case of large stationary and marine engines, and it is a fact that the man who would run a stationary or a marine engine of like power, with as large a coal consumption as is used in the case of the locomotive, would be deemed a very wasteful man and unfit for his business. Of course, the peculiar duties of a locomotive, and the special conditions under which it has to work, may not, and probably will not, enable us to realize as great economy as we do in the other cases, but it is certain that a little earnest, scientifically conducted work would enable us to realize more economy than we do, and how much more we cannot predict until more attempts have been made in a thoroughly scientific manner.

Even where tests have been made, we find a laxity allowed in them which would not be tolerated in making tests of a marine or stationary engine. As an example, I have frequently looked over the results of some locomotive test, hoping to gain some information from it, and when I came to examine the way in which the test was made, found that the conditions were such as would render it entirely untrustworthy if it had been made on a stationary or a marine engine, and I cannot see how the fact that it is a locomotive makes the test where there is so much looseness any more trustworthy. To cite the various improper things that are done in this regard would take too much time, and I will only mention one which has been done altogether too often, viz.: applying the steam engine indicator to one cylinder alone, and guessing that the performance of the other is like unto it. The chances of reaching the truth are not much, if any, greater than if the whole estimate had been made by guessing, and this latter course would have saved work. But we are coming to the time when our railroads can no longer afford to disregard questions of economy of fuel; and these matters are, slowly it is true, but surely, coming into prominence.

One evidence of the state of affairs to which I refer is the remarkable indifference that existed only a few years

ago in regard to the introduction of the compound locomotive. It had at that time already been introduced into Europe for several years, and although it had not really gone very far beyond the experimental stage, it had, nevertheless, been so far developed that it had been experimentally proved without question that a decided saving of coal could be effected by its use. Nevertheless, I listened to discussions among railroad men held at that time where very little interest was shown in furthering its introduction here, and where I heard grave doubts expressed as to whether it would be wise to introduce it into America, and when they attempted to give their reasons for these doubts, they would raise all sorts of objections as to very minor points which it would be very easy to adjust to our needs by the exercise of a very little American ingenuity and adaptability. The compound locomotive, however, came to America, and came to stay; and so prompt have Americans been to adopt it, that we now manufacture a great many in this country.

Of course, those that we have made are decidedly American and not copies of European styles, and most all of our large locomotive works now build more or less of them; and naturally we have a number of different styles, inasmuch as they have been planned and worked out by different men.

But now, if we are going to imagine that there is gain in the simple fact of compounding without regard to how it is to be done, what proportions of cylinders should be employed and what other arrangements should be used, we shall not realize the economy that we might, and we may even fail to realize any; since it will be perfectly possible for a well-proportioned and well-made single locomotive to be more economical than a badly made compound one. If, on the other hand, the introduction of the compound locomotive is to mark the beginning of an era when the same criteria of accuracy and reliability shall be applied to determine the value of a locomotive test as are applied in the case of stationary and marine engines, where we demand and perform more or less experimental work with scientific accuracy; and if the same sort of work

shall be demanded and performed in the case of the locomotive, then the benefits conferred by the introduction of the compound locomotive will not be confined to the cases where it is used, but will also react in bringing into being a more economical class of single locomotives, while it will also cause us to adopt in the design of compounds such features as will be conducive to the greatest economy of coal.

I suppose that after having said so much about compound locomotives, I ought to say a few words by way of explaining what is a compound locomotive, and what is the reason why we are justified in expecting any greater economy with it than with a single locomotive.

In the single locomotive there is one steam cylinder on each side near the forward end, and the steam from the boiler enters each of these cylinders, and causes the respective pistons to move. Before the motion of the piston in either cylinder is completed, however, the steam supply is cut off, and the piston is caused to complete its stroke by the expansive force of the steam. Then during the return stroke the steam on this side of the piston escapes into the exhaust, while that which enters on the other side of the piston is pushing the piston the other way and doing the work.

Thus, in the single engine, the steam enters the cylinder, is cut off at a certain fraction of the stroke, expands, and then escapes directly into the air; and this series of actions is carried on in each cylinder independently of the other, there being really two separate engines connected to the same shaft with the cranks at right angles to each other.

Now, in the compound locomotive, the steam, when it comes from the boiler, enters one cylinder called the high-pressure cylinder, but, when it has expanded in this cylinder, it does not escape into the air, but into another and larger cylinder, where it expands again, and acts upon another piston by its expansive force, and then, from this cylinder, it escapes into the air.

Again, there are a variety of such arrangements that can be made; thus, we may have one high-pressure and one low-

pressure cylinder on each side of the locomotive, *i. e.*, one compound engine on each side, making a pair of compound engines. This arrangement is called a four-cylinder compound. Another arrangement is made by having only two cylinders for the whole locomotive, the high-pressure cylinder on one side and the low-pressure (a larger) cylinder on the other side. A third arrangement is by having one compound engine on each side of the locomotive, the high pressure being inside of the low pressure, the latter being annular and having an annular piston. Then still another method, which is English, is to have two high-pressure cylinders, one on each side of the locomotive and one large low-pressure cylinder underneath, in the middle.

Now, these different arrangements are made by different builders, and each one claims advantages for his own. As to which is best, when the proportions are correctly adjusted, only careful and accurate experiment can determine. As to the reason why we should expect any gain by compounding, it is merely because the difference of temperature of the walls of the cylinder, when the steam enters and leaves it, is less, and hence cylinder condensation should be less, in a good compound than in a single engine, since the expansion is all completed in one cylinder in the latter, whereas it only completes its expansion in two cylinders in the former.

Besides this, there are a great many questions of interest and of importance to be made the subject of careful investigation, in connection with railroads and locomotives. I cannot pretend to give a list, but will mention a very few, as follows: The law of variation of train resistance, or the force necessary to draw the train at different speeds; the air-brakes, about which a number of questions should be investigated; heating, ventilating and lighting cars, etc. Thus, heating of passenger cars by steam from the locomotive has come to stay, and has become so much of an accomplished fact, that it has been adopted on a large number of roads, and will have to be on all; but there are a great many different possible ways of accomplishing it just as there are many ways of heating a building, and

there has hardly any progress been made as yet in regard to ventilating passenger cars.

But I think I have said enough to give you an idea of what a multiplicity of engineering questions arise, and what an amount of engineering work and opportunity for investigation there is about a railroad.

Bridges.—The greater number of our largest bridges are built to form a portion of a railroad, for, in this case, heavier loads are to be supported than when they form a part of a highway. The Brooklyn suspension bridge, which possesses the second longest span in the world, is no exception, for it carries a cable railroad. Their construction is sometimes undertaken as that of public works, as, for instance, by the city or town, and at other times it is carried on by private enterprise. The city, the railroad company, or other corporation, may impose on its own engineer the task of producing the entire plans, both the foundations and the superstructure; or it may delegate the making of these plans to another engineer or to some bridge-building firm; or, on the other hand, in the case of the latter, it may be only the superstructure which is entrusted to the firm to construct, while the foundations are kept as a separate undertaking to be built by the road itself beforehand. When an engineer has to plan a large bridge, it often happens that the foundation is by far the most difficult part of the work. Thus, at the places where the foundation is to be established there may be clay or hard sand, and, on the other hand, there may be quicksand or mud. He may have to build the foundations on piles, if it is not too large a bridge, or he may have to excavate, sometimes to a great depth, before he reaches something that is suitable for a foundation.

Then, again, he may have to establish his foundation under water, and here he may be called upon to perform a great deal of excavation. If it is to be far under water, he may have to resort to pneumatic caissons; and now by the use of machinery we are finding the means of establishing foundations under water at a depth too great to permit of the use of pneumatic caissons. In any of these cases there is a large amount of engineering involved in planning the

work, and also in executing it. A thorough examination of the ground has to be made, including the taking of borings to ascertain how deep the excavation will have to be before something is found which is suitable for a foundation, and the nature of that something. Then the plans have to be made and all necessary calculations to determine what should be constructed, and how it should be built.

Next comes the building of the foundations, and this may involve a large amount of engineering work, especially if pneumatic caissons have to be used, and if part of the work is to be built under water, as the whole erection will involve the introduction of a large amount of machinery, including the use of compressed air, cranes which have to be operated by some kind of power, hoists, etc., and the greatest care will have to be exercised in sinking and locating the caissons, and in preventing them from getting out of place while the excavations are in progress, and in preventing accidents. Then, when the excavation is made, the whole must be adjusted and all must be properly filled up with concrete, and then the masonry can be built above. Of course, this sort of work with difficult foundations is not the every-day work of the engineer in general, but all varieties of foundations are met with where the piers cannot be built directly on the ground, and where we must either build on piles or must have recourse to coffer-dams, and thus be able to excavate the earth until we reach a suitable foundation, or where some sort of crib has to be built, which shall confine a certain amount of loose and flowing sand, and thus render it suitable to build upon. Moreover, the matter of securing a good foundation is an all-important prerequisite for building a bridge that is to stand. Otherwise our bridges would share the fate of those of the old Romans.

Then comes the designing of the bridge, in such a way that it shall have sufficient strength in all its parts to resist the stresses coming on those parts. Moreover, in this work care must be taken to figure every detail, and nothing must be disregarded, for if one of the minor details be neglected in the calculation, this neglect may lead to disaster. It is

very common now, however, for a railroad company to build, or have built under its own direction, the masonry foundations for all the bridges on its road, to *erect* all of them itself, but to have them built, and sometimes also designed, by some bridge-building firm. Now, when the designer, whether he belong to the railroad or to the bridge works has made the design, and has worked out the stresses in all parts of the structure, including all the details, pins, rivets, fastenings, hangers, anchors, etc., and has also made the detail drawings of the bridge, these drawings, or rather the blue prints, can be sent into the shop, and the construction of the bridge can begin.

Making the design, the calculations and the drawings, of course, requires engineering work, and especially an application of the strength of materials, to see that every detail is of the proper strength and stiffness. But I propose to call your attention especially to what engineering work has to be done by the bridge builder in fitting up his shop to do this kind of work properly; and this will be made most evident by a consideration of the engineering problems which one who carries on a bridge works has to solve, and the engineering work he has to execute.

Of course, the method of carrying on the manufacture of bridges, and the amount and character of the engineering work involved, will depend upon the magnitude of the works, which may be small or large, and which may be built for the purpose of merely manufacturing the bridges from iron or steel which they buy, or which may be attached to, or form part of, an iron or steel works.

If they are very large and are connected with an iron and steel works, they may begin with the ore, and make their own pig iron, then transfer it to the Bessemer converters, or to the open hearth furnaces and make the ingot steel, or to the puddling furnaces and make wrought iron. Then the product is rolled, or squeezed, or hammered into blooms, and then these are cut into suitable lengths, and after being heated again, are rolled into angle irons, channel bars, T-irons, Z-bars, plates, etc.

By way of illustration, we will consider the following brief

outline of the method followed at Phœnixville, *i. e.*, at the Phœnix Iron and Steel Company's Works. At one time they used to make their own pig iron, but now they buy it and convert it in their open hearth furnaces into steel.

After having been in the reheating furnace, the ingot goes to the first set of rolls, where it is rolled into blooms, and then to a powerful shears, where it is cut into the lengths needed for different purposes.

In connection with these rolls and shears, which are very heavy, there is some ingenious machinery for performing what may be called the handling of the ingot, *i. e.*, for placing it in the right position on the rollers which feed it into the rolls or shears, for tipping it over when it is desired to do so, etc.

Of course, provision is made in this portion of the works for quick and convenient handling of the heavy ingots, etc., by means of trucks and cranes.

Then from the blooming mill the blooms are placed on trucks, which are drawn by a small locomotive to the rolling mill, where they are heated again, and then rolled into the desired shapes, angles, channel bars, I-beams, etc., and these are then cut off to the proper lengths by saws. In cases where it can be done, the sawing is performed while the steel is hot; but in a number of cases it has to be done when the steel is cold. Then, after leaving the rolls, the beams, channels, angles, etc., are straightened in machines with which the shop is fitted for this purpose. There are also certain machines specially designed to cut the ends in various shapes, such as are needed in fitting different pieces together in the manufacture of a bridge.

The rolling mill is, of course, fitted with a complete system of trolleys and other devices for handling the material, for delivering it to the rolls, for receiving it when it has passed through, transferring it to the next place through which it has to pass, etc. When the beams, channels, angles, etc., come from the rolling mill they are ready for the market, or to be used in the manufacture of bridges.

Then, there is the bridge shop, where all the different pieces that are to compose the separate girders and the

other parts of the bridge are assembled, and the necessary punching, drilling and riveting is performed.

Of course, this shop must be large enough to admit of whole girders being put together, and also easily handled and worked upon. Here, therefore, there are provided ample floor space, large and powerful travelling cranes to handle very heavy material, and punching machines, drilling machines and riveting machines in very considerable number. Of the latter, some are hydraulic riveting machines, conveniently located for the work they have to perform, but fixed in position; while others are portable riveters, operated by compressed air. Then there are many other machines which I will not stop to enumerate. Then, in the yard is a travelling crane, used to load the separate girders and the other parts of the bridges on to cars.

The works are very extensive, and there are numerous other shops used for various special purposes, but I shall not speak of them, as I am not attempting to give you all the details of the Phœnix Works, but only to illustrate to you what kind of operations have to be carried out and what kind of engineering problems present themselves for solution outside of the design of the bridge.

Now, in such works everything that can be done to save labor in handling, or in any other way, is, of course, so much gain. Hence the absolute necessity for a complete system of trolleys, etc. Then again, since holes for rivets and other purposes have to be located, and other features marked by template, whenever some more expeditious method has not been devised, you will find that the various bridge works endeavor to devise some machine to perform as much of the punching or drilling as possible without using a template. This becomes of special importance in the case of the long lines of rivet holes that have to be made in the plates and angle irons which are used to form the flanges and webs of plate girders; so, at these bridge works we find a machine devised for this special purpose.

Without going further into detail, it is plain, after a bridge is designed and the drawings are all made, and it is ready to be constructed, that in connection with the works a large

amount of engineering work must be performed. Of course, the planning and building of the shops in such a way as to be well adapted to their intended purpose, the selection and arrangement, the devising of suitable machinery, some of which (and sometimes considerable) is special machinery, the arrangement of the power plant, and the entire arrangement of the cranes, trolleys, etc., for handling the material, and for loading the finished structures on to the cars to be carried to their destination, all involves a large amount of engineering; and this does not cease with the establishment of the works, for the same kind of engineering questions are constantly arising—questions of mechanism, questions of strength of materials, questions of steam, etc.

At the New Jersey Iron and Steel Company's works electric cranes are used, and some of the machinery in the bridge shop is driven by electric motors. At Edgemoor, is another bridge works where the entire arrangement has been recently laid out with especial reference to convenience and ease of handling, and also to the use of special machinery, and I will outline briefly some of the methods followed in these works in order to show the sort of planning that was performed.

The material is received by rail in the yard, and is taken off the cars, and placed on little trucks running on narrow gauge tracks, on which it is rolled along and taken into the shop.

There are numerous lines of rails, parallel to one another and leading to different parts of the shop. These rails extend the whole length of the shop in one direction, and hence, the motion of any piece in the lengthwise direction is accomplished by means of these trucks. When, however, the material is to be moved in a transverse direction, it is carried by chain falls attached to trolleys moving on rails on the ceiling laid in a direction at right angles to the rails on the floor. This system of rails on the floor running in one direction and rails on the ceiling running in a direction at right angles to them is adopted throughout the greater part of the shop; but when the larger

pieces have already been formed, they are handled by means of a series of jib-cranes actuated by hydraulic power, in which the jib can be made to rise, and lift the piece, and also to turn around, while the chain falls can be moved lengthwise along the jib.

This method of handling the material is peculiarly adapted to such work, because the pieces that have to be handled are mostly long and narrow.

Next, as to the special machinery in use. The following is the method of making the eye bars from a straight bar. The straight, flat bars of proper size are taken to some small furnaces where the ends are heated; then, when hot, the ends are put flatwise into an upsetting machine actuated by hydraulic pressure, where they are upset, and formed into the proper shape for the head by being squeezed between suitably formed dies. This having been done, the bar is at once carried to a hydraulic punching machine, where the hole for the eye is punched usually before the end of the bar has had time to lose its heat. When the eyes have been punched it is straightened if necessary, and then taken to the boring machine, where there are two tools, by means of which both eyes are bored at once.

Then the eye bars are taken on the trucks to the annealing furnace. Here a number of them are put into the furnace together and annealed.

There is also at these works a multiple punch with a specially designed feeding mechanism for the purpose of punching the holes in the plates, angles, etc., of a plate girder, or of any other construction of this character, as in the case of a bridge column. The remainder of the machinery I shall not refer to.

Of course, there have to be powerful pressure pumps to provide pressure for all the hydraulic machines, of which there are many and powerful ones, such as the upsetting machine, the straightening machine, the punches for the eye bars, the hydraulic jib-cranes, etc.

It is plain that the planning and putting up of such a shop, with proper regard to economy of labor and economy in all parts, involve a large amount of engineering, and

of the kind that would usually be called mechanical rather than civil engineering, although the building of bridges has commonly been associated with the latter.

Certain styles and sizes of bridges can be made at the works and shipped to the places where they are to be erected; but when they become very large, they outgrow the capabilities of the bridge works, and a great part of the construction, if not all of it, has to be performed on the ground. In these cases a great deal of engineering work of very varied character is often involved.

Perhaps it will be well to illustrate the character of the work that may have to be done by referring to examples of one or two modern bridges, first making a few general remarks:

(1) While some very large wooden bridges have been built, and while there are still in existence in the United States a great many more bridges built of timber than there ought to be, nevertheless, they are rapidly disappearing, and bridges of any considerable size and importance are no longer made of timber.

(2) Masonry bridges are limited in span.

Hence, the modern bridges of long spans are built of iron or steel; and the necessity is constantly arising to cross greater and greater widths; and, every little while, one is built with a span greater than any that has preceded it. Thus, the famous Britannia tubular bridge, built by Robert Stephenson, in 1850, had two central spans of 459 feet each, and shore spans of 230 feet each, and was thought at the time to be a triumph of engineering. It carried the railroad across the river in rectangular wrought-iron tubes.

To us, to-day, it and others built like it look old-fashioned and cumbrous. Since then many girder bridges have been built in various parts of the world.

By way of arched iron bridges we have quite a number, but the most noteworthy are the two hat were built over the Douro River, at Oporto, Portugal, and the Garabit viaduct, over the Truyère River, in France, all of them having been built by Mr. Eiffel, and having spans of 525, 571 and 541 feet, respectively.

Of suspension bridges I will only mention the Brooklyn bridge, with a span of 1,595 feet, designed by Roebling, and opened in 1883.

At the time this bridge was built, this was the longest span in the world, and it has not yet been outdone by any other suspension bridge; but now we have the Forth bridge with a span, of 1,700 feet; how long it will be before a bridge is built with a longer span is difficult to say.

The central span of the Brooklyn bridge is 1,595 feet in length between the two towers. These towers are built on solid rock, 78 and 45 feet, respectively, below high water, and the tops of the towers are 277 feet above high water. The clear headway at the center is 135 feet. There are four suspension cables, 15½ inches diameter, each made of 5,282 galvanized steel wires, side by side, without any twist. The width of the bridge is 85 feet. At the center, and 12 feet higher than the rest of the bridge, is a footway 15½ feet wide; then the passages for teams are on the outside and the cable railroad between the footway and each of the passages for teams.

When it is necessary to span a considerable width, and to leave a considerable clear height underneath the bridge, and when it is either not possible, or not allowable, to build false work underneath, we have to build the bridge out from the supports. Whereas several bridges have been built out from the supports by dint of special contrivances, the two kinds that would seem to be best adapted to it are sus pension bridges and cantilever bridges. A cantilever is the name given to a bracket fixed at one end and free at the other, the loads being placed either at the free end of the bracket or anywhere along it. Now, in order to render a bracket or cantilever able to bear a load, it must be fastened in some way at the fixed end so that it will not tip over, since the other end is free. Also, the cantilever, if loaded at the end, needs to possess a greater resistance the nearer we approach the fixed end, hence it should have a greater depth at the fixed than at the free end. Now, the idea of a cantilever bridge is to have projecting from each of the two supports a bracket or cantilever, these two projecting brackets

approaching each other, and covering a large part of the distance to be spanned. Then a plain bridge girder is hung from, and supported by, the two free ends of the two cantilevers, and spans the remainder of the distance.

Now some provision has to be made to keep the cantilevers and their supports from tipping over. This is accomplished by having another bracket extend from each support in the opposite direction, and tying down the free ends of these brackets in some way, as by tying them down to weights of sufficient magnitude resting on the ground, or by any other means that will hold them down.

Hence, we find that cantilever bridges have a bracket, deepest at the supports, extending out each way from the support, the river bracket supporting at its free end one end of the central truss, while the end of the shore bracket is tied down in some way. In cases where it cannot be tied down, as where there are two cantilever spans in succession, of course the two brackets projecting from the middle support in opposite directions are easily balanced as far as dead load is concerned, and then sufficient stability to take care of the moving load must be given by providing a sufficiently large base for the pier or support to rest upon, the moving load bearing, of course, a small proportion to the dead load.

The cantilever bridge over the Niagara River near the Falls, was the first bridge ever erected in the United States, and in the world that deserves the name; although in one sense any continuous girder bridge might be called a cantilever bridge, and although several bridges have been cantilevers during the building, *i. e.*, they have been built out from the supports, such as the Douro bridges, or the St. Louis bridge.

This cantilever bridge over the Niagara was designed by Messrs. Schneider, Field and Hayes. It was contracted for on April 11, 1883, and opened on January 1, 1884. The river span, or distance between the piers, is 470 feet; the distance from each shore abutment to each tower is 195 feet, each tower panel being 25 feet, and each river arm 175 feet, while the central girder is 125 feet long, and the total length, exclusive of the approaches, is 910 feet.

The largest cantilever bridge in the world, and also the one having the largest span, is the Forth bridge. This is a railroad bridge, and crosses the Firth of Forth not far from Edinburgh. The estuary at this place is very much exposed to heavy gales and rough seas, but just here is the island of Inchgarvie, situated about half way across; and this was the only place in the entire width of the stream where an intermediate support could be established. To bridge the distances from Inchgarvie to the north shore, and from Inchgarvie to the south shore, would require very long spans; thus the spans actually adopted in the Forth bridge were 1,700 feet, whereas, in 1873, a company had actually begun the erection of a suspension bridge at this same place, the spans of which were to be 1,600 feet each, but the destruction of the Tay bridge by the wind in 1879 brought about the discontinuance of the work, and the decision was made to erect a cantilever bridge. The plan was approved in 1881, the work was begun in 1883, and the bridge was opened in March, 1890. There are, as has been explained, two river spans; hence, in the bridge proper we find three supports, one on the north shore, one on Inchgarvie, and one on the south shore. Each of these supports or towers has a cantilever projecting from each of its two sides, or, if we call a tower and its two projecting cantilevers a double cantilever, we have, in the bridge proper, three double cantilevers. Then uniting these in the two main spans are the two central girders. Of course, the roadway is very far up above high water, and hence there are long approach viaducts on both the north and the south sides.

The dimensions are as follows: Total length of bridge, including the approach viaducts, 8,296 feet, or excluding them, 5,330 feet. The central tower on Inchgarvie, 260 feet long; the other two, each 145 feet. Each of the six cantilevers is 680 feet. Each central girder is 350 feet. This makes each clear span in the river about 1,700 feet.

Each of the three towers is supported on four circular granite piers, so placed that the centers of the four form the corners of a rectangle, whose width is in all three cases 120

feet, but whose length is, in the case of the tower on Inchgarvie, 270 feet, and, in the case of each of the others, 155 feet.

The greater length on Inchgarvie was necessary in order to give the middle tower sufficient stability, since it could not be tied down like the other two. On top of these piers rest the towers, each of which consists of four columns well tied together by suitable bracing. These columns approach each other, two and two as they rise, so that their centers at the top form a rectangle only 33 feet wide instead of 120, the length of the rectangle being the same as at the base. Of course, there are skewbacks between the bases of the columns and the piers.

While the materials were brought from elsewhere, practically all the work had to be performed on the ground, hence it was necessary to build and equip very large works. These were situated on the south shore, whereas smaller works had to be established on the north shore and on Inchgarvie, and easy means of communication had to be established between them, and between them and all parts of the work, for freight, for passengers, and also by means of the telephone. Moreover, the works had to be fitted with a very large amount of machinery, a great deal of which was special machinery designed for this particular work, as will be seen later.

The planning, erecting and superintending of these very large works alone involved an enormous amount of engineering of all sorts, the design and purchase of some, and the manufacture of other machinery, the erection of shop buildings suitable for their purpose, the arrangement of the machinery, the selection and arrangement of the various power plants, the establishment of a complete system of electric lighting, of a complete system of telephonic communication, of complete facilities for travel of the workmen by boat and by rail, and for the carrying of the materials to the points where they were needed, by rail or boat, as well as the establishing of all the machinery for handling the material, as cranes, etc., and of the means of running this machinery; the establishment of suitable means of receiv-

ing and distributing the materials, the steel, the fuel, the cement, the sand, etc., the plants for making and distributing compressed air, and a host of other matters, including the erection of a very considerable number of houses for such of the workmen as could not easily find quarters elsewhere. The amount of engineering work required to carry on all this properly is so great that it is difficult to form an adequate conception of its magnitude. In order to aid in the formation of this conception, I will give a few figures illustrating the enormous scale of the operations involved in this work, before I proceed to the further description of the details of the bridge and of the work.

The total amount of steel used in building the bridge proper, *i. e.*, the three double cantilevers and their two central girders, was about 51,000 tons. The total number of rivets used is uncertain, but is considerably in excess of 6,500,000.

There were used, up to November 30, 1889, 64,315 cubic yards of concrete, and 48,356 cubic yards of rubble, and 27,429 cubic yards of cut stone. The provision for carrying materials from the works on the south shore to the places where they were needed consisted of four steam launches, eight large steam barges, and a lot of barges or lighters which were towed by some of these.

To carry the workmen to and from work, and from one station to another, they provided a paddle steamer capable of carrying 450, and also used the steam barges and steam launches, and besides this they had to have a number of special trains run on the railroads.

Now we will proceed to consider a few of the details.

The entire weight, of course, is taken at the bases of the columns that compose the towers. These columns rest on skewbacks, which, in turn, rest on the piers, *i. e.*, the column at its base terminates in a flat plate, which rests on another plate, which latter is fixed to the pier. In the case of each tower, one of the four upper plates is rigidly fixed to the lower plate, but the other three are left free to slide on their respective lower plates, in response to change of temperature, or to wind pressure, etc.

At all three stations a large amount of preparatory work had to be done to render it possible to establish the works. Thus, on the south shore, where the works were very extensive, a jetty, 2,100 feet long and 50 feet wide, was built on piles; and on this jetty a number of temporary lines of rails were laid, with sufficient space between them to store a great deal of the material as it arrived. From the shore end of this jetty an incline, operated by a rope and a stationary engine, led to the underworks, and all the material went down this incline, as well as the pipes conveying hydraulic pressure. Branches from the railroad led to all parts of the works to facilitate the delivery of the material to and from the furnaces, shops, etc., where it was operated upon. Of course, there was a full quota of cranes for loading and unloading. Not far from the jetty were laid down launching ways of timber, wide enough to take, side by side, two caissons of 70 feet diameter each. The ground where the works were placed had to be first levelled off in terraces, inasmuch as a great deal of level ground was necessary for the works. Here were established a carpenter's and joiner's shop, a large drawing loft, extensive drill roads, a great deal of space out-of-doors for erecting separate parts, and a great many shops containing an enormous amount of machinery, the greater part of it having been specially designed for these works. This plant kept on growing during all the five years that the bridge was in process of construction, so that the cost of the plant was not far from $2,500,000. On Inchgarvie the rock all over the west end of the island had to be cut down to seven feet above high water, and ground had to be filled in and about 100 yards of sea wall built in order to be able to erect the necessary works there. Also, the whole space between the piers was covered with staging made of iron, its area being 10,000 square yards. The verticals for this staging had to be put in place by derrick cranes, and adjusted at the bottom by a diver, and a pin projected into the rock to hold them. Indeed, the erection of this temporary work alone is worthy to be considered as quite a notable piece of engineering.

It was on this island also that the tests were made to determine the greatest pressure of the wind likely to come against the bridge.

The work was carried on night and day, and hence the entire place had to be lighted, not only the shops, etc., but also the particular parts of the bridge where work was going on. For this purpose, three complete electric lighting plants were built and operated; the one on the south shore, however, was, of course, far the larger.

From this brief sketch it is plain that there was a large amount of engineering of varied character required in establishing the works, and in making preparations for the erection of the bridge. It was like building very extensive shops, furnaces, power plants, special machinery, and providing transportation facilities for five years, with the full knowledge that the works must be no longer operated at the end of that time, but all the machinery and appliances must be sold.

Two of the piers on Inchgarvie, and all four on the south shore, had to be founded so far below low water that they had recourse to pneumatic caissons. I will give a brief description of them, and will endeavor to word my description in such a manner as to explain what is a pneumatic caisson, and how it is operated.

The caissons used in this case were made of wrought iron. Their form on the outside was that of a cylinder surmounted by a truncated cone, the diameter of the cylindrical portion being 70 feet, while the small diameter of the conical part was 60 feet; on top of this was fastened the temporary caisson.

Seven feet above the bottom, we find an air-tight floor, strongly braced. Above this floor is put concrete in such quantity as at first to cause the caisson to float with the desired immersion, and afterwards to cause it to sink. The space below the air-tight floor is in the form of a truncated cone, 70 feet in diameter at the bottom, and 56 feet at the top, this being the working chamber, or the chamber where the excavations are made. Three shafts, each 3 feet 7 inches, connect this air chamber with the top. When the

caisson is in operation, one of these shafts serves for the ingress and egress of the workmen, and the other two for the ingress and egress of the materials.

Now, the height of the entire construction, *i. e.*, permanent caisson with temporary caisson attached on top, must be sufficient to reach above high water when the caisson is fully sunk. A little above the top of the permanent caisson are found the tops of the three shafts already mentioned, and at the tops of these shafts are airlocks, through which entrance into, or exit from, the shafts, and hence the working chamber, is effected.

Of course, the internal construction of the caisson would reveal a large amount of heavy bracing, but I shall not undertake to describe it. We thus have in a caisson, as it were, a huge diving bell, into the working chamber of which we force compressed air. This drives out the water, and the caisson, being so loaded as to descend just the right amount, and the compressed air being let on, the workmen proceed to make the excavation, and the material excavated is drawn up by a hoist through the shafts. After the excavation was completed, and the caisson had been sunk to its final resting place, the working chamber was gradually filled up with concrete, and also the shafts, and they then proceeded to fill the whole up with concrete to the level of low water, and at this level began the masonry piers.

The caissons were built at the launching ways, where they were riveted up with hydraulic riveters. When completed, they were launched at high tide and towed to the end of the jetty, where the temporary caisson was attached, and the machinery, etc., was put on, and then they were towed to position.

The granite piers were begun at 18 feet below high water, *i. e.*, at low water level, and here the diameter of each pier was 55 feet, and they were built up to 12 feet 8 inches above high water, the diameter here being 49 feet.

When the piers had reached a level of seven feet below high water, a staging was built at the height of the bedplate on which the columns of the supports were to rest. By

means of this staging, and a template of the bed plate, the holding down bolts were put in place and built in. There were forty-eight holding down bolts in each pier; they were made of a special kind of steel, and had a diameter of two and one-half inches, increased to three inches at the ends where the screw thread was cut.

As much of the work as possible was drilled with all the parts put together; there were a great many special machines, as plate-bending, multiple-drilling, edge-planing, multiple-riveting and others, and portable hydraulic riveters, all specially adapted to the special work to be done.

The work of erection was first carried on to a height of fifty feet above the tops of the masonry piers, and, after that, hydraulic lifting platforms were constructed and used in the central towers. By means of these lifting platforms, the material was raised to the level required, and then it was taken to the point where it was to be used. These platforms were lifted by means of hydraulic rams placed in the central towers. Now, when the cylinder was anchored at any one height, the extent to which the platform could be lifted was the stroke of the ram. When it had been lifted thus far, it became necessary to raise the cylinder of the ram and to anchor it higher up. An ingenious arrangement, which I will not stop to describe, was devised to attain this object. A very ingenious riveting machine and cage was devised and used in doing the enormous amount of riveting which had to be performed in place.

It is plain that the engineering work involved in designing the bridge and its foundations, and making the necessary calculations and drawings, was very decidedly less than that which had to be performed in the construction of the bridge, the latter comprising an enormous variety.

Now, this is the largest bridge in the world, *i. e.*, the one having the longest spans; but engineers are, as a rule, a progressive body of men, and they are constantly devising and erecting works of greater magnitude than any that have gone before, so that it is very doubtful how long it will remain the largest.

Of course, the amount of engineering work involved in

erecting small bridges is far less than in the case of such a bridge as the Forth, but it is all a matter of degree, and the making and erecting of any bridge of any importance requires a great deal of engineering work. Thus, in the case of a moderate sized bridge more or less elaborate works must be on the ground, to handle the material and to perform the work which has to be done there, and which may involve riveting, drilling, punching and a variety of other operations.

Indeed, now that electricity is becoming so much used for the transmission of power, it is not at all unlikely that it, too, will come into play to a considerable extent in the work of erecting bridges and of building them.

Moreover, whereas the designing and building of bridges has been usually associated with the idea of civil engineering, it is plain that a large, if not the larger, part of the work is such as is usually called mechanical engineering; or, rather, it seems to me that we are forced to the conclusion that there is no one portion of engineering that belongs exclusively to civil engineering, and no one portion that belongs exclusively to mechanical engineering, but that all belong to engineering.

Time will not allow me to take up a number of other cases of what are commonly called public works, and which involve a great deal of engineering. Thus, were I to describe to you the details of the piercing of the Mont Cenis or the St. Gothard tunnel, or our own Hudson River tunnel, which, though not completed, is a work of great merit; or were I to describe the operations connected with building canals, as, for instance, the Amsterdam Ship Canal, the Manchester Ship Canal, the Suez Canal, or even the Panama or the Nicaragua Canal, or the operations connected with the improvements of rivers, the building of ports, of docks, etc., you would find again a condition of things similar to that already explained. All these matters require a very large amount of engineering work of all kinds, and also the use of the most modern appliances in the way of machinery of all sorts, including, of course, the steam plant, etc.

[*To be continued.*]

ARMOR PROTECTION FOR HEAVY GUNS IN BATTLESHIPS.*

By Wm. C. Foley.

In a modern battleship, where a high rate of speed is required, one of the chief aims of the designer, in the disposition of the main armament, is to ensure it a maximum protection with a minimum of weight; consequently, wherever weight can be saved without detracting from the offensive and defensive power, or seaworthiness of the vessel, it is of great importance.

The system of mounting the heavy guns singly in several armored stations at a considerable distance apart, interferes with the efficiency of a good auxiliary armament; it increases and complicates the amount of gear necessary for training the guns, and for hoisting the ammunition to the guns; it also increases the weight of armor necessary for protection, as compared with the system of mounting the heavy guns in pairs in a less number of protected stations.

The design that combines great offensive power with a minimum weight of armor, and at the same time has the guns well protected, is the system of mounting the heavy guns in pairs in two armored stations placed at each end of the vessel, and working independently of each other, so that there is no fear of simultaneous disablement from an enemy's gun fire, as in this arrangement all the heavy guns can be utilized with the auxiliary armament for a broadside discharge. To carry guns of the largest calibre now made, ships must necessarily be of large dimensions and heavy displacement, and I think that the very heavy battleships that have been constructed, and are still being built, in foreign navies, are no doubt very good as gun platforms, but they have the drawback of not being such good sea vessels, and the point of seaworthiness has been partly lost sight of in

* Read at the Stated Meeting of the Section of Engineers and Naval Architects, April 24, 1894.

the attempt to form huge floating batteries. These large vessels roll very heavily in a seaway, and the weights being local, so to speak, the strains that are brought to bear on a vessel in such a condition are enormous, to withstand which she must be strengthened in such a manner that the weight of the hull is increased considerably at the cost of the armor protection. The writer believes that in the future, when we have gained more practical knowledge of the working of vessels of this class at sea, the limit of size for a battleship will not exceed 12,000 tons displacement. Thus in reducing the size of our battleships we can increase their number for the same amount of money expended.

As the guns of large calibre that have been tried in different navies have not been altogether successful for various

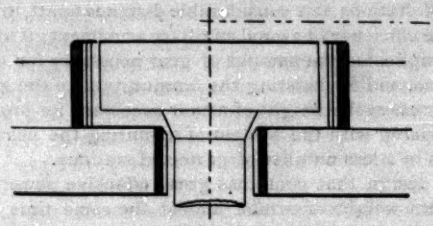


FIG. 1.

reasons, guns of a smaller calibre are now being adopted; in the British Navy, the 13·5-inch, sixty-seven ton gun being used, but the most recent ships will have 12-inch guns. In the Italian Navy they use a gun of sixty-eight tons; and a forty-five ton gun is largely used in the French Navy; and it is probable that the future guns for ships will decrease rather than increase in size, so that for illustration I have chosen a mounting suitable for 12-inch guns.

There are two systems of mountings for heavy guns, both of which are in common use; namely, "barbette mounting" and "turret mounting;" and we will now briefly review the advantages and disadvantages of each.

Barbette Mounting.—In the earlier ships built on the barbette system, the redoubt armor was only carried down

sufficiently to protect the turntable, having a thick plated bottom, the weight of which was transmitted to the hull by a circular support and by the bulkheads below. The ammunition for the guns was either hoisted up direct into the turntable, as in *Fig. 1*, in which case an armored cylinder was carried from the protective deck to the barbette floor, for protection of same; or it was hoisted up at the rear end and outside of the turntable, as in *Fig. 2*.

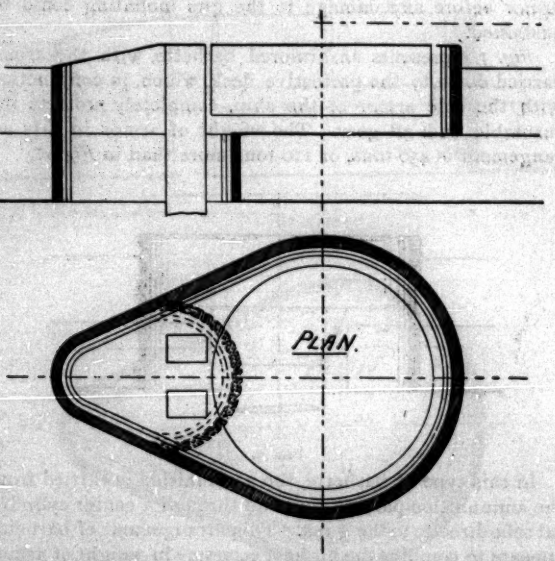


FIG. 2.

In this case the rear plates of the redoubt armor were carried down to the protective deck and an arc of armor worked round the hoists below the barbette floor. The total weight of armor, including a three-inch floor plate, was only 340 tons in *Fig. 1*; and in *Fig. 2*, which is a totally different arrangement, 430 tons. But with the development of quick-firing guns, throwing shells of high explosive power, this

system of armoring barbettes did not afford sufficient protection, as a shell bursting between decks underneath the barbette floor, would throw the turntable out of gear and thus cause the disablement of the guns; therefore, in barbettes, the armor had to be increased in depth, as shown in *Figs. 3* and *4*, an arrangement which completely protects the gun mountings. With this arrangement of armor, a shell bursting inside the ship would have to pierce the redoubt armor before any damage to the gun mounting could be sustained.

Fig. 3 represents an armored barbette, with the armor carried down to the protective deck, which, in conjunction with the side armor of the ship, completely protects the turntable and all gear. The weight of armor in this arrangement is 450 tons, or 110 tons more than in *Fig. 1*.

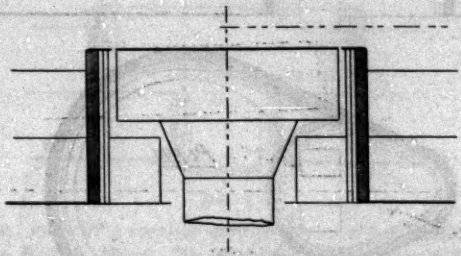


FIG. 3.

In this type of barbette, the ammunition is carried from the ammunition-passing room up through a center cylindrical tube directly to the guns. This arrangement of barbette appears to combine the highest economy in weight of armor with the maximum protection; but its disadvantages are that the carrying of the ammunition directly up into the turntable necessitates the crowding of a good deal of gear into a small space. The rammers also are placed in the turntable, being of the telescopic type; and the turning engine must be situated below the protective deck and geared up to the turning rack. In some designs a hydraulic turning engine is fitted in the turntable, and works with a short

shaft and pinion on to a rack underneath the turntable, but this adds still further to the crowding of gear in the turntable, which is not to be commended.

Fig. 4 represents a barbette with the armor carried down to the protective deck. The armor at the rear end can be decreased in thickness, as in conjunction with any diagonal

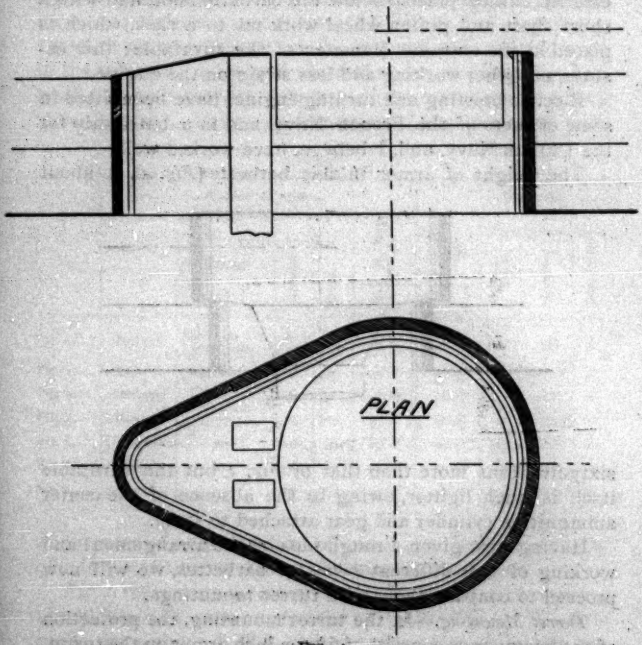


FIG. 4.

armor that may be fitted there is less likelihood of a shot striking here. The armor is shaped as shown in the plan view, *Fig. 4*. The ammunition comes up the hoists at the rear or narrow end, where the rammers are situated, and loads from the cage in the hoists into the guns. In this arrangement the guns have to be trained into the fore and

aft direction, after each discharge, to reload. This is a disadvantage, as compared with the plan shown in *Fig. 3*, in which loading can be done in any position; but a rate of discharge of one round in less than two minutes can be maintained, which is very little below that of *Fig. 3*. The turning engine, which may be either steam, hydraulic or electric, can be placed below the barbette floor, and with a short shaft and pinion wheel work on to a rack, which is placed at the extreme diameter of the turntable; this ensures smoother working and less strain on the engine.

Electric hoisting and turning engines have been fitted in some cruisers of the French Navy, and in a battleship for the Chilian Navy, and, I believe, have worked well.

The weight of armor in this barbette (*Fig. 4*), is about

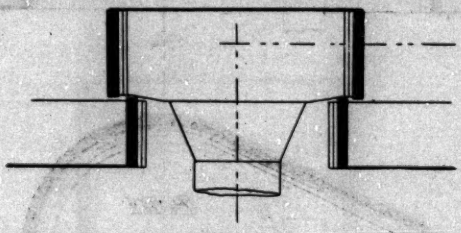


FIG. 5.

sixty-five tons more than that of *Fig. 3*, but the turntable itself is much lighter, owing to the absence of the center ammunition cylinder and gear attached to same.

Having now given a rough idea of the arrangement and working of two different types of barbettes, we will now proceed to contrast them with turret mountings.

Turret Mounting.—In the turret mounting, the protection of the heavy guns consists of fifteen-inch armor on the turret, redoubt armor also being fitted for protection of turret base and ammunition apparatus.

Fig. 5 represents a turret arrangement, the axis of the guns being seventeen feet above L.W.L., the vessel having a freeboard of eleven feet forward; weight of turret and redoubt armor being 406 tons.

Now, for sea-going battleships, a high freeboard forward is advisable, as it is possible to maintain, with such ships, a high rate of speed, and fight the guns in a seaway. In obtaining the freeboard, however, we must keep our weight as low as possible so as to have a stable ship and steady gun platform. At the same time we must not minimize our protection. Although eleven feet is enough freeboard for a coast defense vessel, or for the after end of a sea-going vessel, it is not sufficient for the forward end. A reference to the following table will show that by adopting the barbette arrangement (*Fig. 3*) instead of the turret, we get a deck more forward, giving us a freeboard of eighteen feet with

TABLE.

	Type.	Weight of Armor.			Axis of Guns above L.W.L.	Freeboard.	Thickness of Armor.		
		Turret.	Redoubt.	Total.			Tube, or Turret.	Redoubt.	Base Plate.
Fig. 1, . .	Barbette	{Tube 50 / Base plate 40}	250	340	23′ 0″	18′ 0″	10″	15″	3″
Fig. 2, . .	Barbette	Base plate 40	390	430	23′ 0″	18′ 0″	—	15″, 12″	3″
Fig. 3, . .	Barbette	—	450	450	23′ 0″	18′ 0″	—	15″	—
Fig. 4, . .	Barbette	—	515	515	23′ 0″	18′ 0″	—	15″, 12″	—
Fig. 5, . .	Turret	250	156	406	17′ 0″	11′ 0″	15″	15″	—
Fig. 6, . .	Turret	250	315	565	24′ 6″	18′ 0″	15″	15″	—
Fig. 7, . .	Turret	140	515	655	23′ 0″	18′ 0″	15″	15″, 12″	—

an increase of only fifty tons of armor, the center of gravity of said weight being almost the same in each case.

Fig. 6 represents a turret, the arrangement and working of which are the same as for the barbette, *Fig. 3*. The axis of the guns above L.W.L. is twenty-four feet six inches, but the weight of armor necessary for protection is considerable, namely 565 tons.

But in the turret arrangement the total weight of the turntable exceeds that of the turntable in the barbette arrangement by 300 tons, and this weight it must be remembered is very high up, which is a considerable factor when

the stability is concerned. Then again the power of the turning engines must be increased to turn this extra weight.

Fig. 7 represents a turret mounting, the arrangement and working of which are the same as in the barbette, *Fig. 4*. The total weight of armor, in *Fig. 7*, is ninety tons in excess of that of *Fig. 6*, this increase being in the redoubt armor; but owing to the turntable being lower (thus reducing the depth of the turret armor), the turret armor is 110 tons less in weight than that of *Fig 6*, thus reducing the total weight of the turntable.

Other methods of working turret armor have been tried, such as having the armor on the turrets sloping. This reduces the weight of armor, but it curtails the room inside the turntable; and the armor is also difficult to roll and

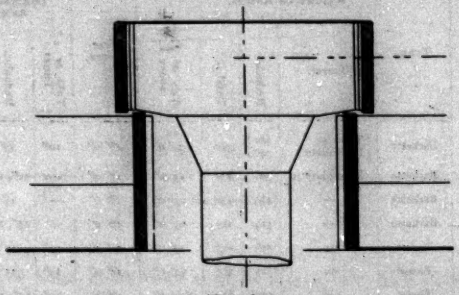


FIG. 6.

machine to the proper bevel at top and bottom. But this can be partly overcome by working the armor plates flat, thus forming a polygon in plan view. This method is adopted in the barbettes in the Italian Navy.

Backing for Armor.—The structure for holding the redoubt armor plates in position is generally formed as follows: Two thicknesses of steel plates are worked for the depth and extent of the armor, stiffened by vertical and horizontal bracket plates and angles, connected firmly to the ship's hull, and the stiffening spaced so as to allow a good disposition of armor bolts. Wood backing is then connected to the outside surface of this structure by means

of galvanized iron or steel bolts, the heads of which are sunk beneath the finished surface of the backing and covered with wooden dowels. Hempen grummets covered with red lead are placed underneath the washer of the nuts on the inside of the two steel plates, to ensure watertightness. The wood backing must be caulked and the seams payed with a waterproof composition; and before fitting the armor plates, a thick layer of red lead, or approved composition, should be applied on the outer surface. The wood backing is trimmed down from a template taken from the armor plate itself, so as to ensure an exact fit. The practice of fitting redoubt armor without wood backing is not to be commended, as there is always a certain amount of working

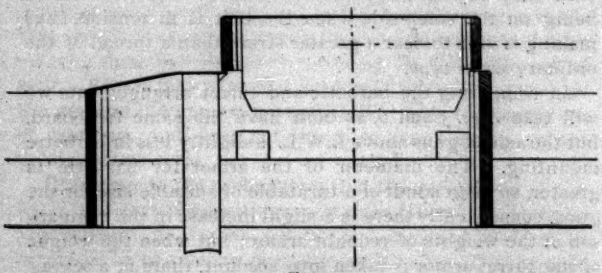


FIG. 7.

in a seaway or from the blast of the guns; and it is easier to heave up the armor bolts and maintain the watertightness of the work when wood backing is fitted. The extra weight due to fitting backing and the slightly increased diameter of armor to fit same, is more than compensated for by the efficiency of the work done.

Armor Plates.—Great care must be exercised in the fitting of the armor plates. They should be made to fit as nearly as possible metal to metal at the butts, and caulked wherever they are so fitted. Where they do not fit accurately, small pieces of metal will be driven into the spaces and then caulked flush with the face of the plate. The plates are held in place by means of bolts, standard sizes being used

for certain thicknesses of armor, the number being proportional to the outer surface of the plate. For fifteen inch armor one bolt is allowed for every four and one-half square feet of surface. Wherever the projection inward from the two thicknesses of plates must be reduced to a minimum, distance sleeves are not fitted, the bolt-head being heaved up against an india-rubber washer in a steel hexagonal cup, thus making the passage of the bolt through the plating water-tight. When no distance sleeve is fitted the weight of the armor is taken on the thread in the plate itself, and not on the thread on the inner end of the bolt, as is usual where space will allow. The threads of armor bolts are similar to the thread of the breech plug of the modern gun, that is, each side of the thread has a different angle, the strain being on the steep side when the bolt is in tension, thus making it able to bear a greater strain than a thread of the ordinary screw type.

In comparing the barbette and turret arrangements we will take *Figs. 3* and *6*, as both have the same freeboard, but the axis of guns above L.W.L. is slightly less in barbette mounting. The diameter of the armor for barbette is greater, so as to admit of a turntable of suitable size for the guns, consequently there is a slight increase in the comparison of the weights of redoubt armor; but when the weight of the turret armor is taken into account, there is a saving in the total weight in the barbette arrangement of over 100 tons, which weight is at a considerable height above L.W.L. Therefore, it may be taken that in the matter of weight and horse-power of turning engine, the barbette has the advantage. It may be said that in the barbette arrangement the guns are more exposed to damage. This is quite true, but it must be remembered that the range of these guns is over ten miles, and that probably in an engagement the firing will commence at a long range, and a gun at this distance is a small object to hit. It is probable, also, that the enemy will aim at the center or highest part of the ship, and if the guns are mounted in pairs at the ends of the vessel the chance of hitting the guns is not much greater than if mounted in a turret.

In the turret arrangement the muzzle of the gun is exposed, and, if hit, is disabled, so that the protection to the guns is not much greater with a turret than with a barbette mounting. Then again, the men are as much protected in the barbette mounting as in the turret mounting, as the top of the turntable or turret is the same in each case, being protected by means of a thick nickel-steel plate, one or two thicknesses of thin plating being worked beneath the thick plate to which it is connected, by means of rivets countersunk top and bottom, to do away with rivet-heads inside the turntable, as a shot striking the thick plate would cause the rivet-heads to fly off, and be a source of danger to those working the guns. Thick steel hoods are placed on top to afford protection for sighting purposes. Another point worth noticing in the turret arrangement is this, that if the turret is struck by a heavy projectile of high velocity there is a chance of throwing the turntable out of gear. This is also a reason for keeping the roller path at the greatest diameter of turntable, as it adds to smoothness of working, and does not bring so much strain on the holding down clips.

Reference to the table shows that the comparison of barbette and turret mountings certainly favors the barbette arrangement, as far as weight is concerned, and as the turntable bases, turning gear, etc. (which after all is the most vital part of the mountings), are equally protected in both cases, the extra weight involved in protecting a small portion of the guns by means of a turret seems to be misplaced, as such extra weight might be employed in increasing the thickness of the redoubt or side armor.

The marked improvements in the manufacture of armor has been the means of a great saving in the weight of armor for a certain amount of protection. The race for supremacy between armor and guns has been carried on incessantly, and as the destructive power and penetrating energy of the projectile has increased, so also the defensive power of the armor has been increased.

From the old armor plate which we can all remember, to the compound armor-plate with a hardened steel face, was a

step in the right direction, and further improvements have furnished nickel-steel and Harveyized armor plates, both of which have given good results, so that now we can use armor of half the thickness and weight formerly used and still have as great protection, and as long as we can use armor around our gun stations to resist penetration, it gives us the advantage of having our guns protected and of being able to strike a blow at any enemy.

In conclusion, the writer hopes he has placed some points before you worthy of discussion.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, May 16, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 16, 1894

MR. JOSEPH M. WILSON, President, in the chair.

Present, forty-six members and six visitors.

Additions to membership reported since last meeting, nine.

The Secretary read a letter from Mr. Thomas P. Conard, conveying his acceptance of election to the Board of Managers.

Mr. E. P. Reichhelm, of New York, read a paper describing the system and apparatus of the American Gas Furnace Company.

Mr. Louis Krumbhaar gave a description of a new apparatus designed for manifolding or producing a large number of printed copies of a document from a stenciled original made on the typewriting machine. The invention consists of an improved printing apparatus, called the "diagraph," which was exhibited and shown in practical operation by the inventor, Mr. Thomas H. Stackhouse.

Mr. Constant de Redon, of New York, exhibited a large number of specimens of aluminum soldered joints, made by the process and material used for the purpose by the Alsite Aluminum Company, of that city. He gave a practical illustration of the method of using the solder, by making a number of joints. Among the numerous exhibits presented by the company were specimens of articles of aluminum handsomely electroplated with gold and silver.

The subjects presented by Mr. Krumbhaar and Mr. de Redon were referred to the Committee on Science and the Arts for investigation.

Mr. Edward Brown described and showed the practical application of a new form of pyrometer devised by him for service in indicating temperatures up to about 2,000°.

The Secretary's report embraced an account of the salient features of the Manchester Ship Canal, which was illustrated with lantern views.

Adjourned. WM. H. WAHL, *Secretary.*

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR APRIL, 1894.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 30, 1894.

GENERAL REVIEW.

The average temperature for March was 48°·0, which is normal.

The average rainfall, 3·62 inches, is an excess of 0·34.

The warmest days were the 17th, 18th, 19th, 20th, 27th, 28th and 30th, and most stations report the 3d as the coldest.

Precipitation was general on the 4th, 5th, 6th, 7th, 8th, 10th, 11th, 19th, 20th, 21st, 22d and 28th. That of the 10th and 11th was a remarkably heavy snowstorm, being particularly severe in the interior and eastern portions of the State. Over two feet of snow fell in some sections and interrupted travel for a short time. The damage to fruit by this storm was less than at first estimated, but many trees were broken and injured, and some early peaches killed.

A heavy hail, rain and thunderstorm, amounting to 5·95 inches, occurred at Somerset on the 28th.

From January 1, 1894, to April 30, 1894, the excess in temperature at Philadelphia was 338°; at Erie, 395°, and at Pittsburgh, 416°.

For the same period the deficiency in precipitation at Philadelphia was 3·32; Erie, 3·22; and Pittsburgh, 0·54.

TEMPERATURE.

	Mean Temperature.	*Mean Precipitation, Inches.*
April, 1888,	46°·5	2·52
1889,	48°·7	4·50
1890,	48°·7	3·46
1891,	49°·8	2·08
1892,	47°·0	2·04
1893,	47°·6	4·74
1894,	48°·0	3·62

The means of the daily maximum and minimum temperatures, 58°·6 and 37°·4, give a monthly mean of 48°·0, which is the normal for the State, and 0°·4 above the corresponding month of 1893.

The average daily range was 21°·2.

Highest monthly mean, 53°·3 at Kilmer.

Lowest monthly mean, 41°·9 at Wellsboro.

Highest temperature recorded during the month, 83° on the 27th at Kilmer.

Lowest temperature, 5° on the 5th at Drifton.

Greatest local monthly range, 69° at Dyberry.

Least local monthly range, 49° at Harrisburg.

Greatest daily range, 50° at Hollidaysburg and Drifton.

BAROMETER.

The mean pressure for the month, 30·06, is about ·06 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·45 at Philadelphia on the 30th, and the lowest 29·45 at Philadelphia on the 11th.

PRECIPITATION.

The average precipitation, 3·62 inches for the month, is an excess of 0·34. The largest totals in inches (including melted snow) were Somerset, 10·00; Wellsboro, 8·69; Lock Haven, 6·42; Le Roy, 6·12; Shingle House, 5·61, and Salem Corners, 5·32.

The least were Altoona, 1·69; Erie, 1·74; Easton, 1·90; Chambersburg, 1·96; Frederick, 2·03, and Beaver Dam, 2·22.

The largest monthly snowfall totals in inches were Salem Corners, 38·2; Lock Haven, 36·0; Selins Grove, 33·0; Le Roy, 32·5; Hamburg, 30·0, and Coatesville, 29·2.

WIND AND WEATHER.

The prevailing wind was from the Northwest.

Average number: rainy days, 11; clear days, 11; fair days, 8; cloudy days, 11.

MISCELLANEOUS PHENOMENA.

Thunder Storms.—Le Roy, 4th, 20th; Quakertown, 20th; Johnstown, 19th, 20th, 28th; Emporium, 20th; State College, 19th, 27th, 28th; West Chester, 20th; Coatesville, 20th; Kennett Square, 16th, 20th, 28th; Phœnixville, 20th, 28th; Grampian, 19th; Lock Haven, 4th, 20th; Bloomsburg, 4th, 5th, 7th, 20th; Saegerstown, 20th; Uniontown, 19th; Carlisle, 20th, 27th, 28th; Huntingdon, 19th, 20th; Kilmer, 20th, 27th, 28th; New Castle, 28th; Coopersburg, 20th, 27th; Pottstown, 20th; Kane, 27th; *Philadelphia* [Weather Bureau], 20th, 28th; [Centennial Avenue], 4th, 20th, 28th; [Locust Street], 20th; Shingle House, 19th, 20th; Selins Grove, 20th, 28th; Somerset, 19th; Wellsboro, 4th, 20th; Lewisburg, 20th, 28th; Dyberry, 20th; Honesdale, 20th; Ligonier, 19th, 20th, 28th; South Eaton, 20th.

Hail.—Le Roy, 20th; Quakertown, 21st; Cassandria, 20th, 22d, 29th; Phœnixville, 10th; Lock Haven, 5th; Bloomsburg, 20th; Sagerstown, 27th;

Carlisle, 20th; Huntingdon, 20th; Greenville, 20th, 28th; *Philadelphia* [Centennial Avenue], 20th; Shingle House, 4th; Selins Grove, 20th; Somerset, 28th; Lewisburg, 20th; Ligonier, 28th; York, 4th, 20th, 28th.

Snow.—Hollidaysburg, 7th; Cassandria, 5th, 7th; Johnstown, 10th, 11th; Emporium, 10th, 11th; Mauch Chunk, 6th, 7th, 10th, 11th; West Chester, 10th, 11th; Coatesville, 10th, 11th, 12th; Kennett Square, 10th, 11th, 12th; Phœnixville, 7th, 10th, 11th; Grampian, 5th, 7th, 10th, 11th; Lock Haven, 7th, 10th, 11th, 12th; Bloomsburg, 10th, 11th; Carlisle, 10th, 11th; Harrisburg, 10th, 11th; Huntingdon, 10th, 11th; Kilmer, 10th, 11th; Lancaster, 10th, 11th, 12th; New Castle, 7th; Lebanon, 7th, 10th, 11th, 12th; Coopersburg, 10th, 11th; Drifton, 4th, 6th, 7th, 10th, 11th; Wilkes-Barre, 10th, 11th; Kane, 7th, 10th, 11th; Smethport, 7th, 10th, 11th; Pottstown, 11th; Easton, 11th; *Philadelphia* [Centennial Ave.], 6th, 7th, 10th, 11th; Shingle House, 7th, 8th, 10th, 11th, 12th; Somerset, 10th; Lewisburg, 10th, 11th, 12th; York, 10th, 11th, 12th.

Sleet.—Le Roy, 5th; Cassandria, 7th, 10th; Phœnixville, 10th; Coopersburg, 11th; Kane, 10th; Logania, 4th, 8th; *Philadelphia* [Locust Street], 6th, 10th; Somerset, 10th, 11th; York, 10th, 11th.

Frost.—Hollidaysburg, 2d, 3d, 6th, 9th, 16th, 26th; Quakertown, 3d, 5th, 9th, 15th, 16th, 23d, 24th, 26th; Cassandria, 2d, 3d, 6th, 7th, 8th, 9th, 26th; Johnstown, 1st, 3d, 6th, 7th, 9th, 11th, 12th, 15th, 16th; Emporium, 2d, 3d, 9th, 13th, 14th, 15th, 16th, 18th, 26th, 30th; Mauch Chunk, 3d, 7th, 16th, 23d; State College, 3d, 6th, 7th, 14th, 15th, 16th, 26th; Grampian, 2d, 3d, 15th; Lock Haven, 3d, 4th, 7th, 8th, 9th, 11th, 13th, 14th, 15th, 16th, 26th; Bloomsburg, 3d; Uniontown, 9th, 15th, 25th, 26th; Huntingdon, 3d, 4th, 15th, 16th, 26th; Kilmer, 3d, 16th, 17th; New Castle, 2d, 3d, 6th, 7th, 8th, 9th, 11th, 12th, 13th, 14th, 15th, 16th, 25th, 26th; Wilkes-Barre, 3d; Kane, 3d, 25th, 26th; Greenville, 13th, 14th, 15th, 25th, 26th; Easton, 7th, 23d; *Philadelphia* [Centennial Avenue], 3d; Shingle House, 16th, 26th, 27th, 30th; Somerset, 9th, 25th, 26th, 27th; Wellsboro, 2d, 3d, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, 16th; Dyberry, 2d, 3d, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 14th, 15th, 16th, 25th, 26th, 30th; Honesdale, 24th; South Eaton, 2d, 3d, 6th, 7th, 8th, 10th, 11th, 12th, 15th, 16th; York, 3d, 6th, 7th, 9th.

Aurora.—Saegerstown, 15th.

Coronæ.—*Philadelphia* [Centennial Avenue], 16th; [Locust Street], 16th.

Solar Halo.—*Philadelphia* [Weather Bureau], 3d, 18th, 27th; [Centennial Avenue], 3d, 18th, 26th; Wellsboro, 27th.

Lunar Halo.—Phœnixville, 18th; Saegerstown, 15th; *Philadelphia* [Weather Bureau], 18th [Centennial Avenue], 18th.

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for April, 1894.

County.	Station.	Elevation above Sea Level (feet).	Temperature.									Precipitation.			Number of Days.			Wind. Prevailing Direction.	Observers
			Mean.	Maximum.		Minimum.		Mean of Maximum.	Mean of Minimum.	Daily Range.		Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Clear.	Fair.	Cloudy.	
				Highest.	Date.	Lowest.	Date.			Mean.	Greatest.								
Allegheny,	Pittsburgh,	820	51·0	82	18	24	9	61·0	40·8	20·2	32	3·63	. . .	. . .	12	12	7	11	NW	O. D. Stewart, W. B
Berks,	Hamburg,	380	49·2	80	27	18	3	59·1	39·2	19·9	40	3·05	30·0	. . .	8	8	13	9	NW	William Shipe.
Berks,	Reading,	280	48·9	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	3·40	. . .	. . .	13	. . .	. . .	. . .	. . .	Franklin Yager.
Blair,	Altoona,	1,181	53·0	76	21	27	3	62·0	44·1	17·9	29	1·69	. . .	. . .	9	. . .	. . .	. . .	. . .	Dr. C. B. Dudley.
Blair,	Hollidaysburg,	947	48·6	81	27 [1]22	14	3	62·7	34·5	28·2	50	3·18	6·0	. . .	10	14	8	8	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	42·8	73	30	16	3	51·9	34·7	16·2	36	0·12	32·5	. . .	16	7	9	14	SW	G. W. T. Warburton
Bucks,	Forks of Neshaminy, [1]	304	51·6	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	3·20	. . .	. . .	9	17	6	7	N	J. C. Hilsman.
Bucks,	Quakertown,	536	48·0	77	27	18	3	58·5	37·4	21·1	39	2·27	7·0	. . .	10	4	21	5	SW	J. L. Heacock.
Cambria,	Cassandria,	2,100	47·8	74	28	20	3, 9	55·0	40·0	15·6	32	3·78	19·0	. . .	12	5	12	13	NW	A. H. Boyle.
Cambria,	Johnstown,	1,284	50·0	82	28, 30	20	3	61·5	38·5	23·0	44	3·99	5·0	. . .	12	6	10	14	S	E. C. Lorents.
Cameron,	Emporium,	1,050	46·7	79	30	16	3	58·0	35·4	22·6	45	3·89	18·4	. . .	11	11	9	10	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	47·2	78	27	16	3	58·4	35·9	22·5	44	3·58	17·5	. . .	11	13	8	9	N	F. C. Wintermute.
Centre,	State College— Agricultural Experimeat Sta.,	1,191	46·8	74	27, 30	18	3	55·8	37·7	18·1	34	3·85	20·5	. . .	11	11	4	15	W	Prof. Wm. Frear.
Chester,	West Chester,	455	49·6	76	28	23	3	58·8	40·4	18·4	31	3·81	7·5	. . .	13	16	7	7	NW	J. C. Green, D.D.S.
Chester,	Coatesville,	380	49·4	79	27	19	2	60·8	38·0	22·8	41	4·20	20·3	. . .	10	12	10	8	W	W. T. Gordon.
Chester	Kennett Square,	275	49·4	78	28	21	3	60·2	38·6	21·6	37	3·80	8·8	. . .	11	15	5	10	S	B. P. Kirk.
Chester,	Phœnixville,	190	50·6	78	27	21	3	62·4	40·8	19·6	35	2·64	12·0	. . .	13	10	6	14	NW	Knowles Croskey.
Chester,	Westtown,	350	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	John D. Carter.
Clearfield,	Grampian,	1,450	46·4	76	30	16	3	56·7	36·2	20·5	38	2·98	12·0	. . .	10	12	4	14	SW	Nathan Moore.
Clinton,	Lock Haven,	560	47·4	82	30	17	3	62·5	36·2	26·3	46	6·42	36·0	. . .	13	14	1	15	W	Prof. J. A. Robb.
Columbia,	Bloomsburg,— State Normal School,	500	48·2	76	27	20	3	57·4	39·0	18·4	35	4·58	18·0	. . .	13	13	4	14	NW	Prof. J. G. Cope.
Crawford,	Meadville— Divinity Hall,	1,200	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prf. J. H. Montgomery.
Crawford,	Saegerstown,	1,200	46·0	80	30	15	3	58·6	33·3	25·3	46	2·55	0·8	. . .	8	6	11	13	NW	J. G. Apple.
Cumberland,	Carlisle,	480	50·0	78	27	20	3	60·6	39·5	21·1	39	3·61	18·5	. . .	10	15	4	11	S	J. E. Pague.
Cumberland,	Carlisle— Dickinson College,	480	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	H. E. Smith.
Dauphin,	Harrisburg,	361	50·0	76	27	27	3	58·0	42·0	17·0	31	2·27	18·0	. . .	11	12	5	13	N	F. Ridgway, W. B.
Delaware,	Swarthmore— Swarthmore College,	190	51·2	80	28	24	3	60·3	42·0	18·3	32	2·62	5·0	. . .	6	8	15	7	NW	Prof. S. J. Cunningham.
Erie,	Edinboro, [2]	1,400	45·3	74	30	20	3, 9	. . .	. . .	. . .	. . .	. . .	10·0	. . .	. . .	. . .	. . .	. . .	W	C. F. Sweet.
Erie,	Erie,	681	45·0	67	19	24	3	52·0	38·0	14·0	30	1·74	. . .	. . .	12	8	16	6	NE	P. Wood, W. B.
Fayette,	Uniontown,	1,000	50·1	81	18	22	3	59·0	41·2	17·8	36	3·50	. . .	. . .	11	9	15	6	NW	Wm. Hunt.
Franklin,	Chambersburg,	618	48·2	76	20, 27	20	3	59·8	36·7	23·1	40	1·96	. . .	. . .	9	10	9	11	NW	J. C. Boggs.
Fulton,	McConnellsburg,	875	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	T. F. Sloan.
Huntingdon,	Huntingdon— The Normal College,	650	48·8	79	27	16	3	62·5	35·2	27·3	46	3·19	9·0	. . .	10	15	7	8	W	Prof. W. J. Swigart.
Indiana,	Indiana— State Normal School,	1,350	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prof. S C. Schmucker.
Juniata,	Kilmer, [2]	475	53·3	83	27	18	2	. . .	. . .	. . .	. . .	4·86	28·1	. . .	11	11	6	13	W	R. J. Mickey.
Lancaster,	Lancaster— Franklin and Marshall Col'ge,	413	49·2	76	20, 27	23	3	59·4	39·0	20·4	34	4·30	17·5	. . .	10	14	11	5	NW	W. E. Bushong.
Lawrence,	New Castle,	932	47·4	81	18	13	3	60·5	34·4	26·1	45	2·94	0·0	. . .	7	11	11	8	S	Wm. T. Butts.
Lebanon,	Lebanon,	458	48·4	77	27	17	3	59·1	37·8	21·3	38	4·77	25·2	. . .	12	13	7	10	NW	G. W. Hayes, C.E.
Lehigh,	Coopersburg,	520	49·4	77	28	20	3	59·5	39·3	20·2	35	3·18	10·0	. . .	9	13	12	5	NW	Dr. M. H. Boye.
Luzerne,	Drifton (25 days),	1,683	42·4	73	27	5	5	57·8	27·0	30·8	50	4·52	13·5	. . .	10	8	5	12	N	J. R. Wagner.
Luzerne,	Wilkes-Barre,	575	48·4	80	30	18	3	60·6	36·2	24·4	43	3·42	14·0	. . .	9	16	2	12	W	A. W. Betterly.
McKean,	Kane,	2,000	43·4	76	30	15	9	54·3	32·6	21·7	34	3·39	13·5	. . .	12	12	7	11	SE	C. H. Kemp.
McKean,	Smethport,	1,500	43·8	78	30	14	3	55·4	32·3	23·1	47	4·22	. . .	. . .	9	10	8	12	SE	Armstrong & Brownell.
Mercer,	Greenville— Thiel College,	1,000	47·6	80	18	18	3	60·0	35·3	24·7	40	2·55	1·5	. . .	9	15	6	9	S	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	51·4	81	27	24	3	61·8	41·1	20·7	36	3·20	5·0	. . .	7	16	7	7	W	Charles Moore, D.D.S.
Montgomery,	Skippack,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	B. W. Dambly.
Northampton,	Easton— Lafayette College,	325	49·9	76	27	20	3	58·7	39·8	18·9	31	2·90	4·5	. . .	6	12	7	11	. . .	J. W. Moore.
Perry,	(Aqueduct) Logania,	367	51·4	82	27	19	3	61·0	41·8	19·2	37	4·89	21·0	. . .	14	13	6	11	NW	Richard Calfin.
Philadelphia,	U. S. Weather Bureau,	117	52·0	77	28	27	3	60·0	43·0	17·0	28	2·99	1·2	. . .	10	13	7	10	NW	L. M. Dey, W. B.
Philadelphia,	1529 Centennial Avenue,	120	52·0	80	28	25	3	62·4	42·6	18·8	30	3·22	2·2	. . .	11	13	10	7	NW	John Comly.
Philadelphia,	3011 Locust Street,	100	51·0	77	28	26	3	60·2	41·8	18·4	31	3·52	2·0	. . .	11	13	5	12	NW	K. L. Paddock.
Pike,	Blooming Grove, [2]	. . .	45·0	79	27	26	3, 11	. . .	. . .	. . .	. . .	2·75	6·8	. . .	10	. . .	. . .	. . .	S	John Grathwohl.
Potter,	Shingle House,	1,475	43·0	79	30	11	3	54·7	31·2	23·5	48	5·61	21·1	. . .	16	11	4	15	W	C. D. Voorhees, M.D.
Schuylkill,	Girardville,	1,000	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	E. C. Wagner.
Snyder,	Selins Grove (26 days),	455	46·2	79	27	27	5, 26	57·6	34·8	22·8	43	4·86	33·0	. . .	9	. . .	18	8	SW	J. M. Boyer,
Somerset,	Somerset,	2,250	46·7	76	30	18	3	58·6	34·8	23·8	44	10·00	6·0	. . .	10	3	14	13	SW	W. M. Schrock.
Tioga,	Wellsboro, [2]	1,327	42·9	74	27, 30	14	3	. . .	. . .	. . .	. . .	8·63	26·0	. . .	12	13	5	12	N	H. D. Deming
Union,	Lewisburg,	450	47·4	78	27	17	3	59·0	35·9	23·1	41	4·28	26·5	. . .	14	14	4	12	S	Prof. W. G. Owens.
Wayne,	Dyberry,	1,100	43·8	78	27	9	3	55·4	32·4	23·1	45	2·51	19·5	. . .	11	13	1	16	NW	Theodore Day.
Wayne,	Honesdale,	1,000	44·8	72	17, 30	23	3	55·0	34·7	20·3	36	3·50	21·0	. . .	14	15	3	12	NW	Andrew Thompson
Wayne,	(Salem Corners) Hamlinton,	1,600	44·8	76	30	17	9	52·4	37·3	15·1	34	5·32	38·2	. . .	16	10	5	15	NW	T.B. Orchard, M.D.
Westmoreland,	(Immel Reservoir) Lycippus,	1,420	40·5	80	19	22	9	58·2	40·8	17·4	27	3·99	2·8	. . .	10	. . .	. . .	. . .	. . .	Murray Forbes.
Westmoreland,	Ligonier,	1,750	48·4	80	17, 30	17	3	61·2	34·6	25·6	42	4·71	. . .	. . .	11	12	11	7	. . .	C. D. Ambrose.
Wyoming,	South Eaton,	660	45·8	74	27, 30	15	3	55·4	36·2	19·2	39	2·76	8·0	. . .	13	13	4	13	NW	B. M. Hait.
York,	York,	385	49·8	78	27	21	3	61·1	38·5	22·6	40	4·48	26·0	. . .	12	11	14	5	NW	Mrs. L. H. Grenewald.

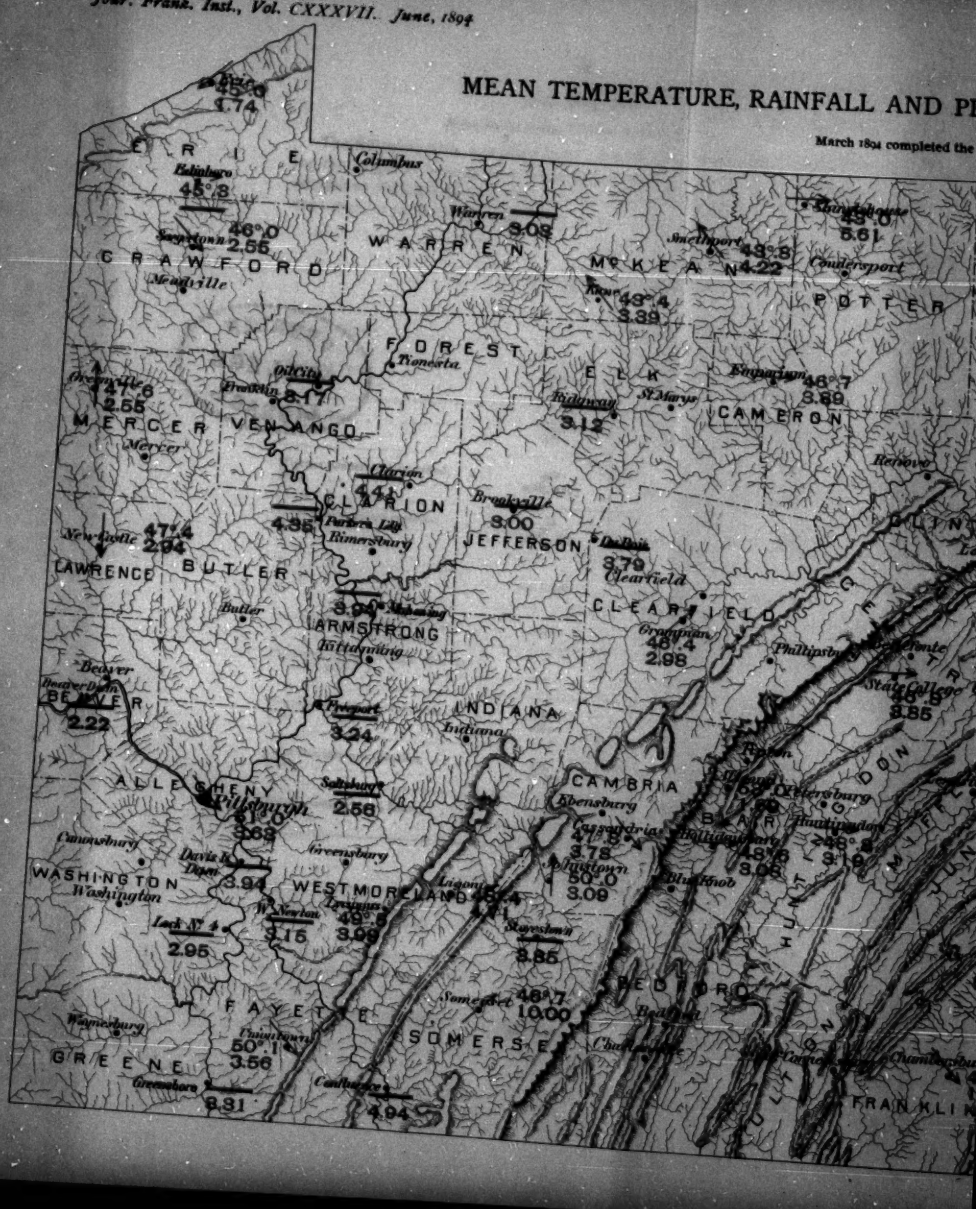
Mean temperature from maximum and minimum readings. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 + 4. [2] Mean temperature 8 + 8 + 9.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,				.89		.31	.11	.25		.41	.98	.03							.30		.37	.36		.10				.25				2.75
Browers Lock,				.33	.02			.19		.46	1.85	.10									.36	.09										2.46
Coatesville,				.53	.02			.29		.97									.01		.30	.18		.05								4.20
Coopersburg,				.62		.03	.07	.24		.44	1.29								.01		.13	.55										3.12
Doylestown,				.49				.14		.55	1.09	.06									.35	.02										3.30
Dyberry,					.02	.05	.36	.18		.30	.70	.30								.03	.22	.16						.19				2.51
Easton,					.37		.05				.85									.02		.60						.01				1.90
Forks of Neshaminy,				.45	.03		.02	.14			1.46										.45	.60		.02				.23				3.20
Frederick,				.43			.03	.2		.46	.81									.03	.18	.29						.28				2.03
Hamburg,				.66			.31			.83	1.10	.33								.09		.25						.06				3.53
Honesdale,				.15	.17	.01	.38	.17		.23	1.07	.30								.04	.22	.28	.04	.04				.20				3.30
Kennett Square,				.57	.09			.19		1.20	1.19	.09					.01			.03	.30	.09						.20				3.80
Lansdale,				.50	.03			.18		.48	.63	.03								.32		.18						.06				2.61
Mauch Chunk,				.19		.08	.20			.39	1.60	.21							.05		.34	.35						.04				3.38
Ottsville,				.68	.02		.05			.27	.46	.02								.01	.19	.53						.01				2.23
Philadelphia, a†				.57	.07		.02	.30		.20	.84										.18	.14						.18	.03			2.99
Philadelphia, b,				.52	.05		.01	.30		.70	.98	.01									.38	.17						.03	.05			3.72
Philadelphia, c,				.62	.06		.01	.30		.05	1.20	.01									.40	.18						.03	.04			3.58
Phœnixville,				.34			.06	.14		.43	.98	.02					.01		.02	.35	.10	.09		.04				.06				2.04
Point Pleasant,				.53			.03			.10	1.40	.36									.73	.57		.02								3.74
Pottstown,				.65			.10	.20			1.75									.30		.10						.10				3.20
Quakertown,				.58		.05	.26	.08			.79	.27								.03	.20	.63						.03				2.72
Reading,				.55			.15	.05		.60	1.35	.20					.01		.01	.01	.07	.01						.04				3.40
Salem Corners,				.15	.17	.18	.08	.36			2.40	.75	.01						.05	.04	.19	.35		.08	.03			.23	.05			5.32
Seisholtzville,				.75			.03	.05		.20	1.32	.06									.68											3.06
Skippack,																																
Smith's Corner,				.56				.15		.20	1.29										.28	.46										2.94
Swarthmore,				.50				.42				1.20									.36	.21						.01				2.60
West Chester,				.60			.04	.15		.99	1.45	.06					.03		.01	.03	.31	.10		.01				.03				3.82
Westtown,																																
Susquehanna Basin.																																
Altoona,							.08	.14		.22	.35								.03	.60	.20							.04	.03			1.69
Aqueduct,	.03			.18	.02		.14	.01		.79	1.56	.08								.04	.82	.07		.03			.08	.05				4.29
Bloomsburg,				.64	.11	.03	.22	.02		.40	1.40						.04		.06	.01	1.15	.48	.02					.38				4.38
Carlisle,				.13			.17			.63	.95	.20							.02		1.03	*	.13			.20		.15	*			3.61
Drifton,	*			.46	.11	.15	.31	*		.20	.75	.50			*						1.40	.38										4.52
Emporium,				.15	.08		.51			.40	.75								.22	.37	.24	.26	.30					.17				3.89
Gettysburg,				.83	.30			.18		.04	1.68	.37								.04	.56	.13						.07	.34			3.94
Girardville,																																
Grampian,				.20		.08	.50			.30	.48								.72	.20	.22							.16				2.98
Harrisburg,†				.18			.20	.02		.36	1.04	.08							.08	.04	.28	.08						.03				2.27
Hollidaysburg,				.04	.09		.32			.66	.63	.03							.59	.36								.10	.06			3.08
Huntingdon,							.04			.70	.68	.10							.12	.08	.29	.07	.10					.10				3.19
Kilmer,				.10		.10	.30			1.21	1.87								.10	.01	.31	.15					.01	.10				4.86
Lancaster,				.70			.30			.35	1.30	.50					.03		.01	.52	.30							.07				4.30
Lebanon,				.50			.23	.02		.75	2.11	.21					.02	.03	.36		.26	.01						.07				4.77
Le Roy,				.15	.03	.04	.31	.15		.15	2.20	.40							.08	.58	.63	.80	.30	.03			.08	.05				6.12
Lewisburg,				.08	.05		.15	.43		.40	1.20	.15					.02		.11	.12	1.25	.67	.01					.04				4.28
Lock Haven,				.16	.15		.44			1.00	2.20	.20					.04		.29	1.38	.04	.40	.06					.06				6.42
Selins Grove,				.21			.40	.05		.07	1.80									.10	1.00	.40						.07				4.86
South Eaton,				.06	.14	.07	.16	.20		.15	.81	.06							.06		.50	.26		.03				.16				2.76
State College,				.04	.01			.30		.50	1.30								.24	.40	.26	.06	.07					.07				3.85
Wellsboro,				.08				.55		.35	1.40	.55			.05				.15	.30	1.36	2.00	1.65					.05				8.69
Wilkes-Barre,				.13	.14			.15			1.30								.10	.29		.44	.05					.22				3.41
York,				.45	.06		.11	.10		.90	1.69	.32							.01		.58	.07						.10	.09			4.48

†U. S. Weather Bureau Stations. * Missing.

URING APRIL, 1894.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,			.05	.02	..	.01	.05	.20	..	.22	.71	..							.08	.56	.05	.05	..						.19			2.22
Brookville,				.11	.07			.47		.22	.53	.08							.12	.96	.73	..	.06					.04	.11			3.00
Cassandria,	.03			.11	.07	.30	.27	.05		.14	.50	.30							.37	.20	..							.24				3.78
Clarion,	.07			.13	.06	.08	.13	.68		.15	1.28	.05							.20	1.40	.05							.14	.09			4.41
Confluence,	.11			.11	.15	.25	..	.78		.44	1.17	.13							.11	.55	.06	.02	.05					.06	.25			4.94
Davis Island Dam,				.06	.01	.13	.03	.32		.38	.70	.01							.15	1.08	.27	.01	.01						.77			3.94
DuBois,				.06	.27	.11	.12	.57		.09	.72	.06								.92	.56	.18	..						.13			3.97
Elwood Junction,				.06	.02		.01	.22		.19	.59								.18	.94	.06	.03	.01						.41			2.80
Freeport,					.06	.14	.04	.38	.28	.91	.09	..							.23	.82	.09	..	..						.27			3.24
Greensboro,				.05	..	.16	..	.75		.30	.40	.10							.20	.40	.02	.07	.06						.80			3.31
Greenville,				.30	.08		.64			.45	..								.47	.47	..	.08	.02					.04				2.55
Immel Reservoir,				.05			.25	.20		.86	..	.33							.47	.72	.10	.20						.88				3.59
Indiana,																																
Johnstown,	.05			.12	.15	.09	.34	.06		.42	.31								.54	.72		.09						.20				3.09
Kane,	.08			.25	.10	.03	.65			.45	.35									1.11	.02						.02	.22				3.39
Ligonier,				.25	.14	.10	.40			.45	.20								.65	.80		.20	.11					1.40	.12			4.71
Lock No. 4,				.03		.18		.44		.46	.67	.05							.04	.83	.04	.03	.01						.17			2.95
Mahoning,				.08	.09	.10	.07	.34		.16	1.06	.02							.29	1.37	.04	.01	.11					.04	.16			3.94
Meadville,																																
New Castle,					.10	.32					.62								.32	1.06	.15							.37				2.94
Oil City,	.02			.17	.05	.10	.11	.50		.15	.70								.29	.68	.16	.02		.02				.10	.10			3.17
Parker's Landing,	.03			.08	.05	.10	.04	.55		.10	1.21	.04							.23	1.31	.19	.03	.12					.05	.18			4.35
Pittsburg,†				.09	.08	.03	.36	.01		.67	.25								.69	.53	..	.04						.43	.35			3.61
Ridgway,	.09			.05	.05	.02	.06	.42		.01	.65	.05								1.08	.30		.22					.12				3.12
Saegerstown,					.40		.30			.05									.60	.10	.40						.30	.20				2.55
Saltsburg,				.02	.01	.20	.02	.28		.24	.66	.03							.05	.76	.06	.02							.21			2.36
Shingle House,	.03			.20	.08		.33	.03		.50	1.20	.05					.03		.08	1.12	.14	.82	.62	.01				.37				5.61
Smethport,				.20			.45			.40	1.20								1.00	.15	.15	.25	.22					.20				4.22
Somerset,						.35	.45			.25	.45								1.05	.25	.50	.10	.25					5.95				10.00
Stoyestown,	.05			.37	.30					.45	.20	.47							.03	.78	.39	.10						.07	.64			3.85
Uniontown,				.06	.05		.76			.49	.36								1.00	.18		.05					.08	.49	.04			3.56
Warren,				.48	.19	.08	.10	.04		.12	.23	.03							.01	.94	.08	..	.04					.65	.04			3.03
West Newton,				.02	..	.12	..	.37		.43	.42	.07							.08	.93	.03	.08							.60			3.15
Potomac Basin.																																
Chambersburg,				.14						.62	.48	.02								.31	.22	.09					.05	.03				1.96
McConnellsburg,																																
Lake Basin.																																
Erie,†				.04	.01	..	.45			.04	.09	..							.55	.19	.06	.01	.04					.25	.01			1.74


MEAN TEMPERATURE, RAINFALL AND PI
March 1894 completed the
ERIE
Columbus
Edinboro
45°.8
1.74
Girard
45°.0
1.74
Warren
3.03
Youngstown
46°.0
2.55
CRAWFORD
WARREN
McKEAN
Smethport
43°.8
4.22
Coudersport
45°.0
5.61
POTTER
Meadville
Kane
43°.4
3.39
FOREST
ELK
Emporium
46°.7
3.89
Oil City
3.17
Ridgway
3.12
St Marys
CAMERON
MERCER
VENANGO
Mercer
Clarion
4.41
Brookville
3.00
CLARION
JEFFERSON
Parker's Ldg
Rimersburg
4.36
New Castle
47°.4
2.94
LAWRENCE
BUTLER
Du Bois
3.79
Clearfield
CLEARFIELD
Butler
3.94
Kittanning
ARMSTRONG
Grampian
48°.4
2.98
Phillipsburg
Beaver
Beaver Falls
BEAVER
2.22
Freeport
3.24
INDIANA
Indiana
ALLEGHENY
Pittsburgh
51°.0
3.63
Saltsburg
2.58
CAMBRIA
Ebensburg
Carrolltown
47°.8
3.78
Hollidaysburg
48°.0
3.05
Huntingdon
Altoona
Johnstown
50°.0
3.09
Blue Knob
Cannonsburg
Greensburg
WASHINGTON
Washington
3.94
WESTMORELAND
Ligonier
45°.4
3.91
Latrobe
49°.6
3.09
Laughlintown
3.15
Lock № 4
2.95
Stoystown
3.85
BEDFORD
Somerset
48°.7
1.00
FAYETTE
SOMERSET
Connellsville
Uniontown
50°.1
3.56
GREENE
Waynesburg
Greensboro
3.31
Confluence
4.94
Chambersburg
FRANKLIN

REVAILING WIND DIRECTION FOR APRIL. 1894

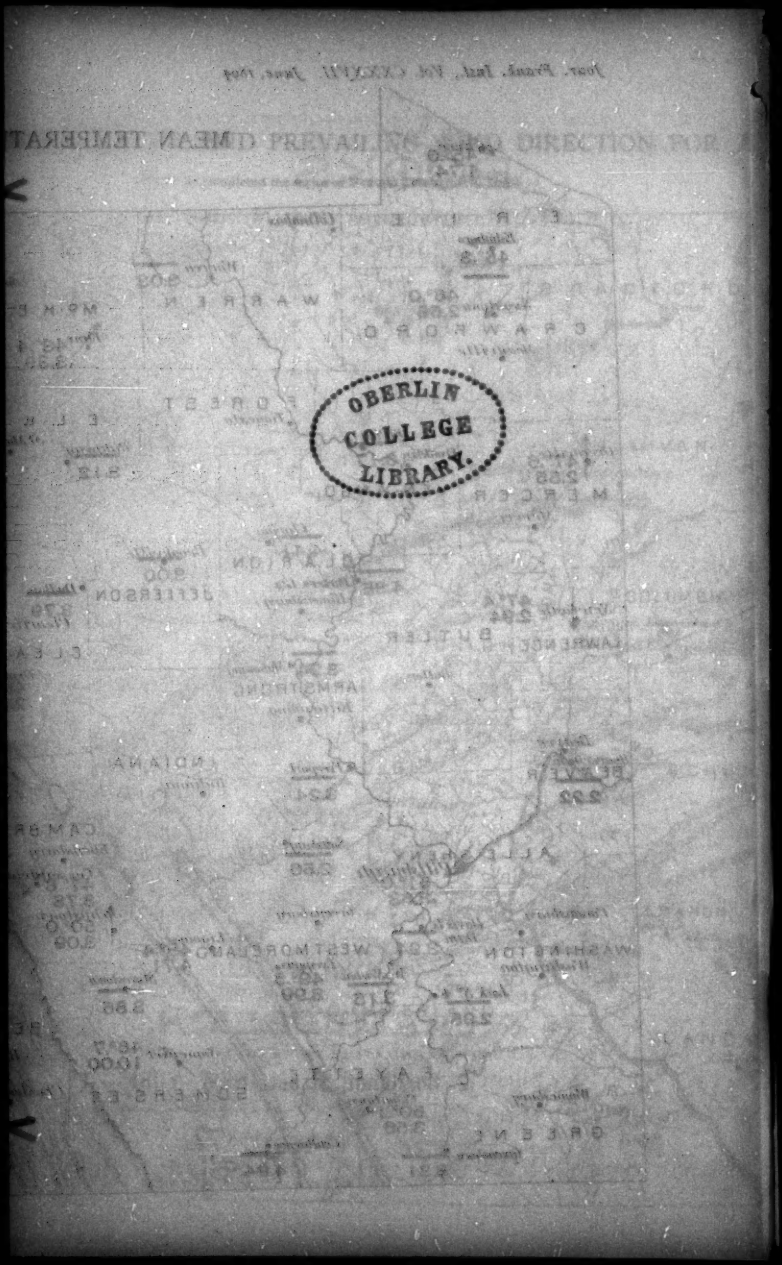
e series of Normal Temperature Maps.

JUNE WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future June.

	Philadelphia. (23 years.)	Pittsburgh. (23 years.)	Erie. (21 years.)
Mean or normal,	72°	71°	67°
Warmest June, Average,	1892 74°	1892 75°	1876 71°
Coldest June, Average,	1881 67°	1878 66°	1881 62°
Highest temperature recorded, Date,	98° 20th, 1893	98° 28th, 1874	91° 28th, 1874; 24th, 1875
Lowest temperature recorded, Date,	47° 15th, 1884	39° 7th, 1879	42° 7th, 1879
Average date of last "killing" frost (spring),	April 9th	April 27th	April 30th
Average precipitation (inches),	3.20	3.63	4.08
Average number of days with .01 inch or more,	10	12	12
Greatest monthly precipitation, Date,	6.81 1887	6.95 1881	6.84 1885
Least monthly precipitation, Date,	0.74 1885	1.47 1876	1.22 1891
Greatest amount in 24 hours, Date,	2.88 22d and 23d, 1887	2.52 9th, 1881	3.64 6th, 1887
Average number clear days, Partly cloudy, Cloudy,	9 13 8	8 15 7	9 13 8
Prevailing direction of wind,	SW	NW	S and SW
Highest velocity, miles per hour, Date,	46 1st, 1889	35 11th, 1890	35 10th, 1888; 7th, 1889; 4th, 1890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